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ROY WALDO MINER

THE RELATION OF LEAN BODY WEIGHT TO METABOLISM AND SOME CONSEQUENT SYSTEMATIZATIONS

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II. Basic Considerations and Data

THE RELATION OF LEAN BODY WEIGHT TO METABOLISM AND SOME CONSEQUENT SYSTEMATIZATIONS *

By

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I. DEVELOPMENT OF FORMULAS FOR THE PREDICTION OF LEAN BODY WEIGHT FROM BASAL METABOLISM

Introduction

The aim of this analysis was to connect human basal metabolism (M) with lean body weight (LBW), by a convenient formula of predictive value. While pursuing this objective, however, there emerged interesting principles of broader scope. In what follows we shall first pursue the original objective, and then analyze certain basic factors and principles.

Benedict[1] pointed out the linear relationship between gross body weight and basal metabolism in various species. However, in each species the data were widely dispersed around lines of general trend, and it was not possible to predict individual metabolism from weight or weight from metabolism.

Kleiber[2] and Brody,[3] on the other hand, related mean metabolism of many species to a fractional power of body weight of the order of 0.73 to 0.75. On a logarithmic plot the linear alignment of their data both for poikilotherms and homoiotherms has been extended from weights of one milligram to weights of more than several thousand kilograms (Hemmingsen[4]).

For the prediction of human metabolism from body parameters it has been necessary to include height (H) in addition to weight. This is accomplished in the classical logarithmic formula of DuBois and DuBois,[5] which calculates surface area from height and weight, and asserts that metabolism is proportional to surface area. Parallel developments were the Harris and Benedict bilinear equations[6] which predict metabolism from height, weight, and age without reference to surface area. Prediction of metabolism for individuals from the DuBois and Harris-Benedict formulas is fairly accurate. Certainly, for groups of individuals, observed and predicted metabolism are nearly identical if allowance (variation of less than 7 per cent) is made for differences in technic employed and the degree of training of the subjects (Boothby, Berkson, and Dunn,[7] and Berkson and Boothby[8]).

*The views expressed in this article are those of the author and do not necessarily reflect the views of the Navy Department, or the Naval Service at large.

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Concept of the Lean Body Mass

Progress toward a more definitive and individual resolution of the relationship between metabolism and weight has been delayed by lack of technics to estimate the fat content of the body particularly in sizable numbers of individuals. During the past 14 years, however, it has been possible to determine accurately *in vivo* the fat content of the body by two unrelated methods, the one a determination of the specific gravity of the body as a whole,[9] the other, a determination of its total water content.[10]

The densimetric studies revealed that fat of density 0.93, was the the chief variable affecting body composition according to a simple inverse relationship such that for every two units decrease in specific gravity from 1.100 [the sp. gr. of the lean body mass (LBM)], the fat content of the body increases one per cent.[9,11] From analysis of carcasses of guinea pigs, this relationship for practical purposes was confirmed. The results of *in vivo* analysis on man were virtually identical with the *in vitro* analyses on the guinea pig.[12,13]

The (upper) limiting value of the specific gravity for several different human populations is 1.100. One may tentatively suppose that this value represents the overall density of a lean body mass whose percentage composition is constant from individual to individual. This concept can be checked *a posteriori* as follows. For a given individual of weight,

$$W = (\mathrm{LBW}) + (\text{fat weight}),$$

one may, with the aid of the foregoing assumption, compute the (LBW). On the *same* individual one may make a direct estimate of total body water (*vide infra*). The percentage of water in the LBW is thus calculable. If our assumption is really true, then the percentage of water in the LBW calculated in this way should be constant from individual to individual. This turns out to be the case.[12,13,14,15] Moreover, direct gravimetric analyses on other mammals indicates that 1.100 is the "density of the LBM" in those cases as well. Such results support the concept that the mammalian body, in regard to such major components as water, protein, and minerals shows little variation throughout the whole period of adult life.[16,17,18] The chief difference between man and lower mammals seems to be the higher mineral and somewhat lower protein content of man.[19] Having this basic concept in mind, we now turn to the relation between LBM and metabolism.

Steele *et al.*,[20] already have pointed out a high correlation between total body water (antipyrine space) and basal metabolism. Dahlström[21] further showed that another component of the LBM, the extracellular

fluid (ECF, thiocyanate space) was correlated ($r = 0.96$) with observed or predicted values for metabolism:

$$\text{ECF (liters)} = 0.0137 \times M,$$

where M is measured in gram-calories per minute, and predicted from the formula of Harris and Benedict. Miller and Blyth[22] have made a noteworthy contribution in their estimation of LBM, from both observed M ($r = 0.924$) and creatinine excretion rate.

Extension of the relationship between M and LBW would permit not only an estimate of body fat from a functional determination but also of components of the LBM and even of such functions as cardiac output.[23]

In this report there will be compiled a series of relationships between surface area (SA), M, and LBW, or W that incorporates a *known* percentage of fat. These relationships form an exceptionally consistent pattern heretofore obscured by unknown quantities of excess fat included in gross weight. Surface area will be shown to be proportional not to the two thirds power of weight ("surface area law") but to $W,^{.73 \text{ to } .75}$ whenever mean weight is related to stature as in a general population. It will be shown further that metabolism of men and women, though some 10 per cent different in terms of surface area, is actually the same per unit of LBW for comparable weights. In addition, a substantial part of the decrease of M with age is accounted for by the mean increase in fat of the general population (about 10 to 20 per cent of total body weight between the ages of 25 and 55). Finally, it will be shown that LBW can be predicted from M by simple power equations (derived from fitting data) whose differential forms can be checked *independently* from a knowledge of the coefficients of variation (standard deviations in terms of per cent of the mean) of LBW and M.

Definitions and Description of Data

Basal Metabolism, Standard Metabolism (Krogh), Metabolism. These refer to the caloric equivalent of the oxygen consumption of healthy individuals relative to CO_2 elimination, under standardized conditions which usually prescribe rest (following normal sleep), the post absorptive state, and normal body and ambient temperatures.

Weight. Throughout this paper the terms, gross weight or weight (W) unless otherwise noted will be understood to consist of a constant percentage of fat, 10 for men, 15 for women.

Units. Weight will be expressed in kilograms, height (H) in centimeters; unless designated otherwise.

Excess Fat. The storage or depot substance in fat cells, not in itself utilizing oxygen but perhaps affecting metabolism indirectly. Excess fat is to be distinguished from metabolically active *fat tissue* which in

lean individuals has about the same blood supply as resting muscle. The basic assumption is that the metabolism of fat cells is independent of the quantity of storage fat present, under conditions of equilibrium. With reference to women, the term, "excess", requires some qualification, perhaps apology.

Lean Body Mass (LBM). This is an *in vivo* entity and its weight (LBW) is the difference between gross weight (W) and the weight of excess fat. It is not identical in composition with the "fat-free" body as determined by post mortem chemical analysis because it contains lipid substances, *e.g.*, myelin, of unknown quantity but probably of the order of 1.5 to 3 per cent. In this paper the LBM is considered to be the "active protoplasmic mass". There appears to be no advantage in eliminating any of the constant fraction LBM components such as mineral or bone.

Indices of the Type, LBW/H, LBW/H². These indices distinguish quantitatively asthenic from pyknic, thin from thick, frail from sturdy, and little from big individuals. $\frac{\text{LBW}}{\text{H}^2}$ provides a quantitative description for "build", independent of stature and fatness. An analogous quantity, the "ponderal index", $\frac{\text{W}}{\text{H}^2}$, has been used by Davenport.[24] The index, $\frac{\text{LBW}}{\text{H}}$, is convenient for comparing individuals of the same stature. For stature of 70 in. (177.8 cm.), $\frac{\text{LBW}}{\text{H}}$, in terms of pounds and inches, has the same numerical value of $\frac{\text{LBW}}{\text{H}^2}$, in terms of grams and centimeters. Since LBW turns out to be proportional to H^2 in the general population, the index, $\frac{\text{LBW}}{\text{H}^2}$ is especially useful, for it eliminates the factor of stature in the comparison of weights. It will be known hereafter as the "LBW index".

Coefficient of Variation. This coefficient makes possible the comparison of variabilities of frequency distributions measured in different units. It is the standard deviation of the distribution expressed as a percentage of the mean of the distribution, *i.e.*, (SD/mean) $\times$ 100.

Surface Area. This refers to a specific height-weight relationship described by the DuBois equation or its linear equivalent. Surface area is describable by either H or W when certain conditions hold. It is the "metabolic" surface area, and may or may not be the actual surface area of an individual. Several factors affect the accuracy of prediction of surface area from height and weight alone. For example, variation in the sp. gr. of the body as a whole precludes interchangeability of volume and weight in the SA formulas. However, the accuracy of the DuBois formulation in conjunction with constants adjusted for age, in predicting basal metabolism of normal individuals has been established within the limitation of the standardized technics currently employed.[7,8] A distinction is to be observed between SA based on H and W, and "SA" (occasionally used) based on H and LBW. For young adults

(25-30 yrs.), M is predicted from SA (DuBois) multiplied by a factor, 40 Cal m^{-2} hr^{-1} (men) and 36 Cal m^{-2} hr^{-1} (women), *i.e.*, a difference of about 4 Cal m^{-2} hr^{-1}. Using "SA", the corresponding difference is 3.3 Cal or 41.8 Cal (men) and 38.5 Cal (women).

Subjects. (TABLE 1, FIGURE 1). These consist of two different groups of Navy men studied in 1940 and in 1950 [Group I (9), Group II (14)] and a group of professional football players (25). Group I, for the most part, were deep sea divers, and Group II were individuals from a medical station. Prior to the laboratory tests an attempt was made (Group II only) to select approximately equal numbers of "endomorphic", "mesomorphic" and "ectomorphic" individuals. From TABLE 1, it is seen that the groups are nevertheless closely comparable. There was no selection of data, and all values are reported except for individuals aged 20 or less who were excluded on the assumption that they were probably not physically mature despite attainment of maximal stature (Randall[26]). In part this judgment was based on the fact that the metabolism per unit of surface area does not plateau until age 25.

The data for the two groups and the groups combined are remarkably consistent; not only does the LBW distribution approach normality (mean value 63.1 kg., median value, 61.8 kg.) but the mean of the LBW distribution at each stature level fell on the LBW-H^2 line for the entire population (the LBW index varied between 1.99 and 2.11). Moreover, the coefficients of variation were practically the same for each group, ±11 per cent. This compactness in the distribution of LBW indicates that more than 90 per cent of individual values lie between 52 and 78 kg.

The professional football players (25) were selected individuals whose frequency of occurrence in the male adult population may be 4 or 5 out of every 100. They were predominantly lean (mean percentage of fat, 10) and big. Their LBW index was 2.44 compared with 2.03 for the Navy men (TABLE 1, FIGURE 1), *i.e.*, these two groups were separated by about two SD's.

Mean Height-Weight Data. These data were compiled by the Actuarial Society of America, 1912,[27] and are referred to as "Standard". Tabular weights for men and women, age 25, are dealt with almost exclusively. No allowance is made for clothing or shoes, since increased height by reason of shoes is compensated for in part by the increased weight of clothing. In any case there is agreement (male weights) with data on 45,904 Army separatees reported by Randall.[28] Moreover, we are primarily concerned with LBW which, judging from body composition results on lower animals, undergoes little change in adult life; metabolism will be related to this weight and not to the variable quantities of fat or clothing. Although the mean stature of the population has increased over a period of 40 years, there are no data to indicate that the con-

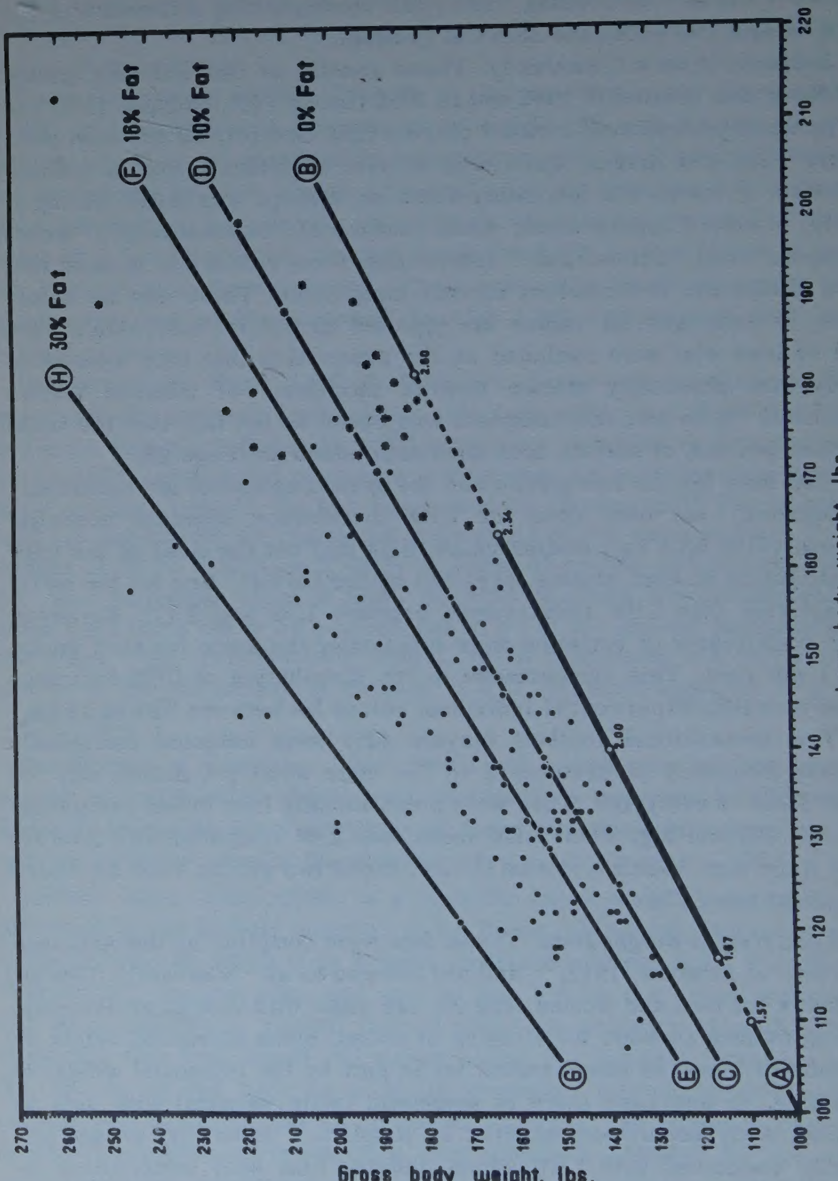

FIGURE 1 *(For description see facing page)*

comitant increase in LBW associated with the higher stature, altered the mean LBW index characteristic of the earlier population.

Logarithmic and Arithmetic Representation of Data. In expressing relations between variables (X, Y, Z, *etc.*) of interest, we shall employ simple power functions, well-known in this field and in theoretical studies of growth and form, *viz.*,

$$\left.\begin{array}{l} Y = aX^b \\ \text{or, } \log Y = \log a + b \log X \end{array}\right\} \text{a, b, constants,} \tag{1}$$

and,

$$\left.\begin{array}{l} Z = aX^bY^c \\ \text{or, } \log Z = \log a + b \log X + c \log X \end{array}\right\} \text{a, b, c, constants} \tag{2}$$

There exist several convenient methods* for choosing a, b, (or a, b, c, as the case may be) in such a way that the equations adequately represent a given set of data. A property of these equations which is not widely known, however, is the following: Differentiation of the logarithmic forms gives, approximately,

$$\begin{array}{c} \frac{\Delta Y}{Y} = b\,\frac{\Delta X}{X}, \text{ or} \\ \frac{\Delta Z}{Z} = b\,\frac{\Delta X}{X} - c\,\frac{\Delta Y}{Y} \end{array} \tag{3}$$

Equations (3) are general, and apply in particular when X, Y, or Z, have their mean values, and ΔX, ΔY, ΔZ, represent deviations from the means. Now the mere setting down of equations (1) and (2), and their consequence, (3), implies that the variables are *perfectly correlated.* This, of course, need not be so, but, *to the extent that this condition is approximated,* one may substitute for the ratios in equations (3) the coefficients of variation ($\frac{\sigma x}{X \text{ mean}}$, $\frac{\sigma y}{Y \text{ mean}}$, $\frac{\sigma z}{Z \text{ mean}}$, etc.), thus establishing relations between the coefficients of variation and the constants (b, c) of the logarithmic equation. In the case of equation (1), this relation is sufficient to determine b. It is interesting, as will be shown below, that these considerations apply reasonably well to the

* For instance, a straight line may be fitted to a logarithmic plot of the data, using the "least squares" method, or the slopes and intercepts of the lines connecting successive pairs of points may be averaged, *etc.*

FIGURE 1. *(See opposite page)* The dots represent individual values on 129 Navy men and the stars corresponding data on 25 football players. The mean fat content (Navy men) is 16.4 per cent, athletes, 9.9 per cent. Mean LBW is 63.1 kg. ±7, (138.8 lb. ±15.2), and mean H, 176 cm. (69.3 in.). Reference point is 2.00 for LBW lb./H. in. (stature 70 in.), and consecutive values range from 1.67 to 2.34 (Navy men) with scattered values designated by the interrupted line. The numerical values for the LBW index, LBW gm./H^2 cm., are practically the same as those for LBW lb./H in. when H is 70 in.

TABLE 1

GROSS BODY WEIGHT, LEAN BODY WEIGHT, AND PERCENTAGE OF FAT IN TWO GROUPS OF NAVY MEN AND A GROUP OF PROFESSIONAL FOOTBALL PLAYERS.

A. DISTRIBUTION ACCORDING TO LBW CATEGORIES

Number 129

	Group		Age		H in.		LBW lb.		Gross W lb.	Excess Fat	$\frac{\text{LBW lb.}}{\text{H in.}}$	$\frac{\text{LBW gm.}}{\text{H}^2\text{ cm.}}$ (index)
Total	I	II	mean	range	mean	range	mean	range	mean	%		
2	0	2	31.5	26-37	65.3	65.0-65.6	108.5	107-110	135.5	20.0	1.66	1.79
11	9	2	32.8	26-42	66.1	65.2-72.0	116.5	111-120	146.0	19.9	1.76	1.88
23	13	10	28.2	21-43	66.9	65.0-71.0	124.5	121-130	149.2	16.6	1.86	1.96
38	20	18	28.2	21-43	69.3	65.6-74.0	134.3	131-140	156.3	14.7	1.93	1.97
26	13	13	28.2	21-38	70.2	66.0-74.5	145.3	141-150	174.1	16.5	2.07	2.08
18	8	10	29.0	22-46	71.2	68.0-74.1	155.8	151-160	189.0	17.5	2.19	2.17
7	2	5	27.3	22-31	72.7	69.6-75.3	163.5	161-170	201.1	18.8	2.25	2.18
4	1	3	27.5	23-32	73.2	71.0-76.3	174.8	171-177	194.3	10.3	2.39	2.30
mean			29.0		69.3 (176 cm.)		138.8 (63.1 kg.)		161.1	16.4	2.00	2.037
					median ----		136.0 (61.8 kg.)		SD (LBW)	±15.2 lb.,	Coef. Var.	10.9 %

	LBW index
Group I, N-66, H in. 69.4 (176.3 cm.), LBW lb. 136.2 (61.9 kg.)	1.99
Group II, N-63, H in. 69.2 LBW lb. 141.4 (64.3 kg.) SD (LBW) ± 15.7 lb.	2.08

Football players	Age	H in	H in.		LBW lb.		W lb.	%	LBW	
	mean	range	mean	range	mean	range	mean	Fat	H	LBW index
N-25	25.2	22-31	72.1	68.7-75.3	180.1	165-213	200.6	9.9	2.50	2.44

B. DISTRIBUTION OF LBW ACCORDING TO STATURE (NAVY MEN)

H in.	65	66	67	68	69	70	71	72	73	74
N-130	7	17	14	16	17	15	17	11	6	10
Mean LBW kg.	54.2	57.8	58.5	60.1	62.9	66.6	65.2	67.2	68.5	70.4
LBW index	1.99	2.06	2.02	2.01	2.05	2.11	2.00	2.01	1.99	1.99

variables with which we are concerned. A word should also be said about linear approximations to equations (1) and (2). These can either be deduced "by eye" or by the least squares method, given a plot of the points. Given not the data, but the power equation, say $Y = aX^b$, in the range, X', Y', to X'', Y'', one may also deduce the linear approximation from the least square principle. In this case the constants in the approximation, $Y = AX + B$, are:

$$A = \frac{\frac{4}{b+2}(X''-X')(X''^2Y''-X'^2Y') - \frac{2}{b+1}(X''^2-X'^2)(X''Y''-X'Y')}{\frac{4}{3}(X''-X')(X''^3-X'^3) - (X''^2-X'^2)(X''^2-X'^2)}$$

and

$$B = \frac{\frac{4/3}{b+1}(X''^3-X'^3)(X''Y''-X'^2Y') - \frac{2}{b+2}(X''^2-X'^2)(X''^2Y''-X'^2Y')}{\frac{4}{3}(X''-X')(X''^3-X'^3) - (X''^2-X'^2)(X''^2-X'^2)}$$

Applying any of the foregoing methods to the data relating mean H to mean W in the general population, one obtains the following approximate equations:

$$H = 21.0\ W^{.5}$$

$$W = .00227\ H^2$$

$$LBW = .00204\ H^2$$

Estimate of Lean Body Weights from Gross Weights, Age 25, Given in the American Standard Tables

Male Weights. For the combined Navy groups, the mean LBW is 63.1 kg. (138.8 lb.) for mean stature of 176 cm. (69.3 in.), or about 2 lb./in. H, (LBW index, 2.037). From TABLE 2, W corresponding to stature 175.3 cm. (69 in.) is 69.5 kg., and for stature 177.8 cm. (70 in.), it is 71.4 kg. The difference between mean W (population) and LBW (Navy) is approximately 10 per cent.

For the different mean weights corresponding to the statures of the general H-W curve, the percentage of fat for any given age is assumed to be constant. The general population weight curve shifted 10 per cent to the left (FIGURE 2) is an approximation, therefore, to the LBW curve for American men, age 25. The Navy data for increments of stature are fewer in number, but the mean values are not too widely separated from the general population values calculated as 0.9 W, age 25, (FIGURE 3).

Female Weights. For women there are insufficient specific gravity or total body water measurements to form a reference value comparable to

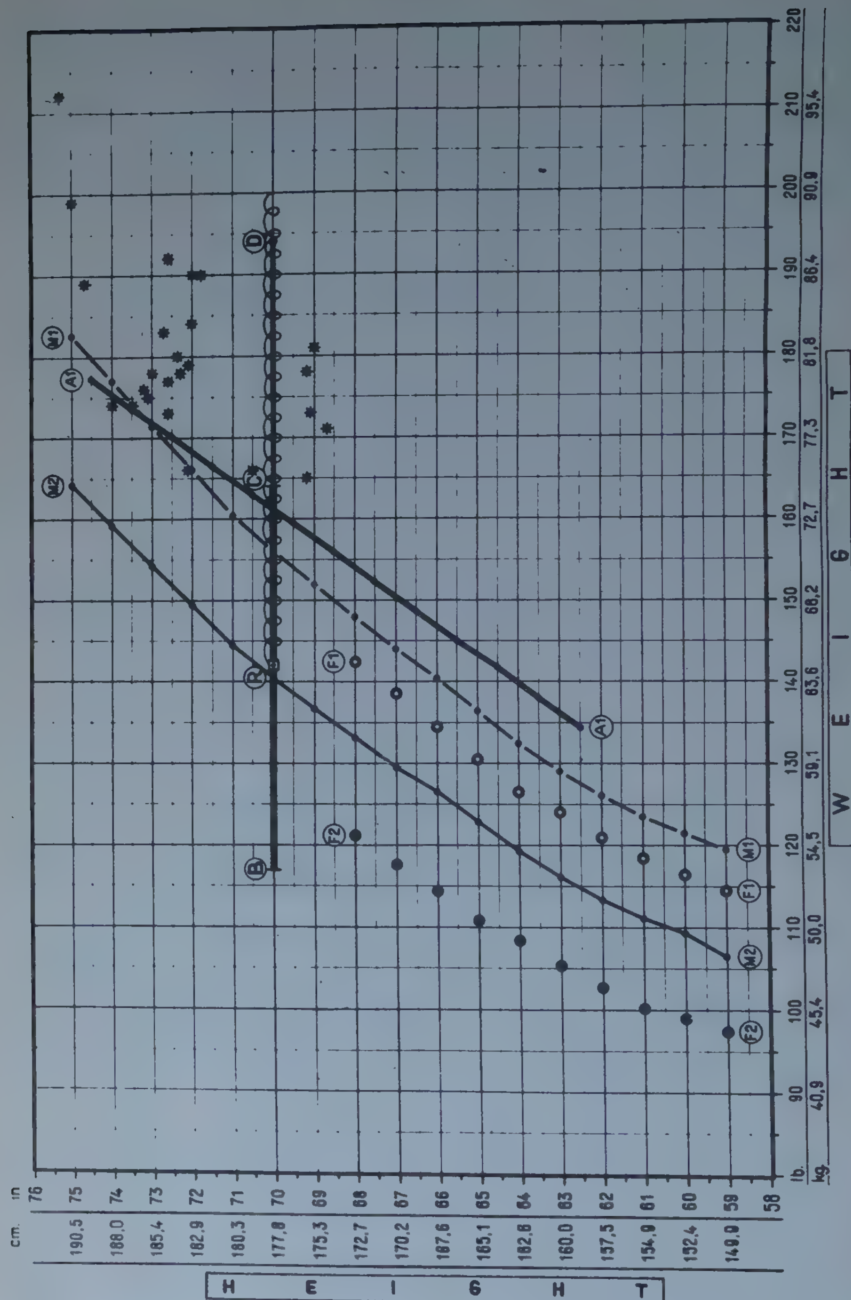

FIGURE 2 *(For description see facing page)*

the index of 2.037 for men or the value of 2 lb./in. H (69-70 in.). A value of 15 per cent fat corresponding to the 10 per cent value for men is an approximation derived from measurements of skin folds by Edwards,[29] from the difference between male and female fat ratios in guinea pigs whose percentage fat distribution was similar to that for man, and from the sex difference in metabolism per unit of surface area. This will be discussed in a subsequent paragraph.

Mean Body Fat Percentages for Various Ages
American Population

It is again repeated that the gross morphologic components not only of small mammals but also of cattle undergo little change after "chemical maturity" is attained (Moulton[18]). If this uniformity in composition of LBM holds for man, at least prior to senility, then the following percentages of fat for various age groups can be calculated (Stature is not considered to be a variable influencing these percentages).

Age	20	25	35	45	55
Men					
W (H 69 in.)	67.3	69.5	72.7	75.0	76.4
LBW (Index 2.04)	62.7	62.7	62.7	62.7	62.7
% Fat	6.8	9.8	13.8	16.4	19.2
Women					
W (H 64 in.)	56.8	58.2	60.9	64.1	65.4
LBW (Index 1.87)	49.4	49.4	49.4	49.4	49.4
% Fat	13	15	18.9	22.9	24.5

These estimates are not without their arbitrary aspects and depend upon population weights selected and the mean values for LBW relative to stature. Brozek and Keys[30] record lower values for LBW, *viz.*, 62.4 kg. for a group of 133 university students, age 20.3 yr., 177.8 cm.

FIGURE 2. *(See opposite page)* Estimated LBW from gross weights of the general population, age 25.

A_1-A_1, mean W, Army separatees, average age 23.

M_1-M_1, mean W, men, age 25 (27); M_2-M_2, mean LBW (.9 W).

F_1-F_1, mean W, women, age 25 (27); F_2-F_2, mean LBW (.85 W).

B-C, range of consecutive values of LBW (Navy men).

R, reference point for approximate mean LBW (63.6 kg., 140 lb.) for H, 177.8 cm. (70 in.)

R-D, range of excess fat in Navy men (1.5 to 38.5 % W).

Stars, LBW of football players.

TABLE 2

ESTIMATED LEAN BODY WEIGHTS FOR WEIGHT DATA FROM STANDARD TABLES FOR ADULTS, AGE 25, AND WEIGHT DATA FROM ARMY SOURCES ON 45,975 SEPARATEES, AVERAGE AGE 23, RANGE 19 TO 31.

MEN		Weight			LBW			Weight (Army)	WOMEN		Weight			LBW		
in.	H cm.	(1)	(2)	(3)	(1a)	(2a)	(3a)		in.	H cm.	(5)	(6)	(7)	(5a)	(6a)	(7a)
61	154.9	56.4	54.4	53.8	50.8	49.0	48.4		57	144.8	50.4	46.1	47.8	42.8	39.2	40.6
62	157.5	57.3	56.2	55.8	51.6	50.6	50.3		58	147.3	51.4	47.7	49.3	43.7	40.6	41.9
63	160.0	58.6	58.0	57.8	52.7	52.2	52.0	61.0	59	149.9	52.3	49.4	50.8	44.5	42.0	42.2
64	162.6	60.5	59.9	59.8	54.4	53.8	53.8	62.7	60	152.4	53.2	51.1	52.4	45.2	43.4	44.5
65	165.1	62.3	61.8	61.8	56.1	55.6	55.6	64.3	61	154.9	54.1	52.8	53.9	45.9	44.9	45.8
66	167.6	64.1	63.7	63.7	57.7	57.3	57.3	65.9	62	157.5	55.0	54.6	55.4	46.8	46.4	47.0
67	170.2	65.9	65.6	65.7	59.3	59.1	59.1	67.5	63	160.0	56.4	56.3	57.0	47.9	47.9	48.0
68	172.7	67.7	67.6	67.7	60.9	60.8	60.9	69.3								
mean									mean							
69	175.3	69.5	69.6	69.7	62.5	62.6	62.7	70.8								
70	177.8	71.4	71.6	71.7	64.3	64.5	64.5	72.4	64	162.6	58.2	58.2	58.5	49.5	49.4	49.7
71	180.3	73.6	73.7	73.6	66.2	66.3	66.2	74.0	65	165.1	59.5	60.0	60.0	50.6	51.0	51.0
72	182.9	75.9	75.8	75.6	68.3	68.3	68.0	75.6	66	167.6	61.4	61.8	61.6	52.2	52.5	52.3
73	185.4	78.6	77.9	77.6	70.7	70.1	69.8	77.3	67	170.2	63.2	63.7	63.1	53.7	54.2	53.7
74	188.0	81.4	80.1	78.6	73.7	72.1	71.6	78.9	68	172.7	65.0	65.6	64.6	55.3	55.8	54.9
75	190.5	82.3	82.2	81.5	74.1	74.0	73.4	80.6	69	175.3	66.8	67.6	66.2	56.8	57.5	56.3
76	193.0	85.9	84.4	83.5	77.3	76.0	75.1	82.4	70	177.8	68.6	69.5	67.7	58.3	59.1	57.6
77	195.5	88.2	86.6	85.5	79.4	77.9	76.9		71	180.3	70.0	71.5	69.3	59.5	60.8	58.8

Column

(1), (5) Standard weights[27]

(1a) LBW = .9 W. (5a) LBW = .85 W

From power formulas

(2) $W = .00227\,H^2$, (2a) $LBW = .00204\,H^2$, LBW index = 2.04

(6) $W = .00223\,H^2$, (6a) $LBW = .00187\,H^2$, LBW index = 1.87

From linear formulas

(3) $W = .78\,H - 67$, (3a) $LBW = .7\,H - 60$

(7) $W = .606\,H - 40$, (7a) $LBW = .515\,H - 34$

(70 in.) tall. Brozek[31] later reported a "fat-free" weight of 60.5 kg. referable to young men 176 cm. tall. These values are similar to that for our Group I, *viz.*, 61.9 kg. (176 cm.) but the value for Group II was larger, 64.3 kg. Miller and Blyth[22] reported mean values of 68.9 kg. for a group of physical education students (athletes) (H, 179.2 cm.), and 63.2 kg. for medical students (H, 177 cm.). The LBW indices for the respective groups are 2.44 (athletes) and 2.017 (medical students). It is interesting to note that the index for the Miller-Blyth athletes is the same as for our football players (TABLE 1).

TABLE 3

BASIS FOR THE ESTIMATION OF THE EXCESS FAT (W − LBW) OF THE AMERICAN POPULATION FROM 3 POSSIBLE LEVELS OF THE MEAN LBW INDEX FOR MEN AND WOMEN.

		Mean LBW index (1)	H	LBW (2)	W (3)	Age (4)	SA m^{-2} (5)	Cal m^{-2} hr^{-1} (6)	Cal hr^{-1} / LBW
1.	men	1.96	175.3	60.2	66.9	20	1.821	41.6	1.258
	women	1.80	162.6	47.6	56.0	18	1.603	37.0	1.246
2.	men	2.00	175.3	61.5	68.3	22	1.842	40.9	1.225
	women	1.83	162.6	48.5	57.1	21	1.619	36.2	1.208
3.	men	2.04	175.3	62.7	69.7	25	1.861	40.3	1.196
	women	1.87	162.6	49.4	58.1	25	1.637	36.0	1.193

(1) LBW gm./H^2 cm.

(2) LBW gm. = LBW index × H^2 e.g., LBW gm. = 1.96 $(175.3)^2$.

(3) 10% fat (men), 15% fat (women).

(4) Age corresponding to W, Standard H-W tables[27].

(5) SA $cm.^2 = 228.5\ W^{.55} \times H^{.4}$

(6) Mayo Clinic Standards[7].

The LBW indices for all of the groups cited, vary from 1.95 to 2.08 if the athletes are excluded. An index of 2.00 for men and a corresponding value of 1.83 for women are reasonable middle values and may be associated with Standard tabular weights, age 22, on the basis of 10 per cent fat (men) and 15 per cent fat (women). In TABLE 3 several combinations of indices are presented which are in accord with the experimental data for men, of various investigators. The values assigned to women are the estimates of this author.

Surface Area and Lean Body Weight

Values for "SA" predicted from observed LBW and H (DuBois formula) for Navy men and football players are plotted against observed LBW in FIGURE 4. The resulting coefficient of correlation is 0.94. This figure

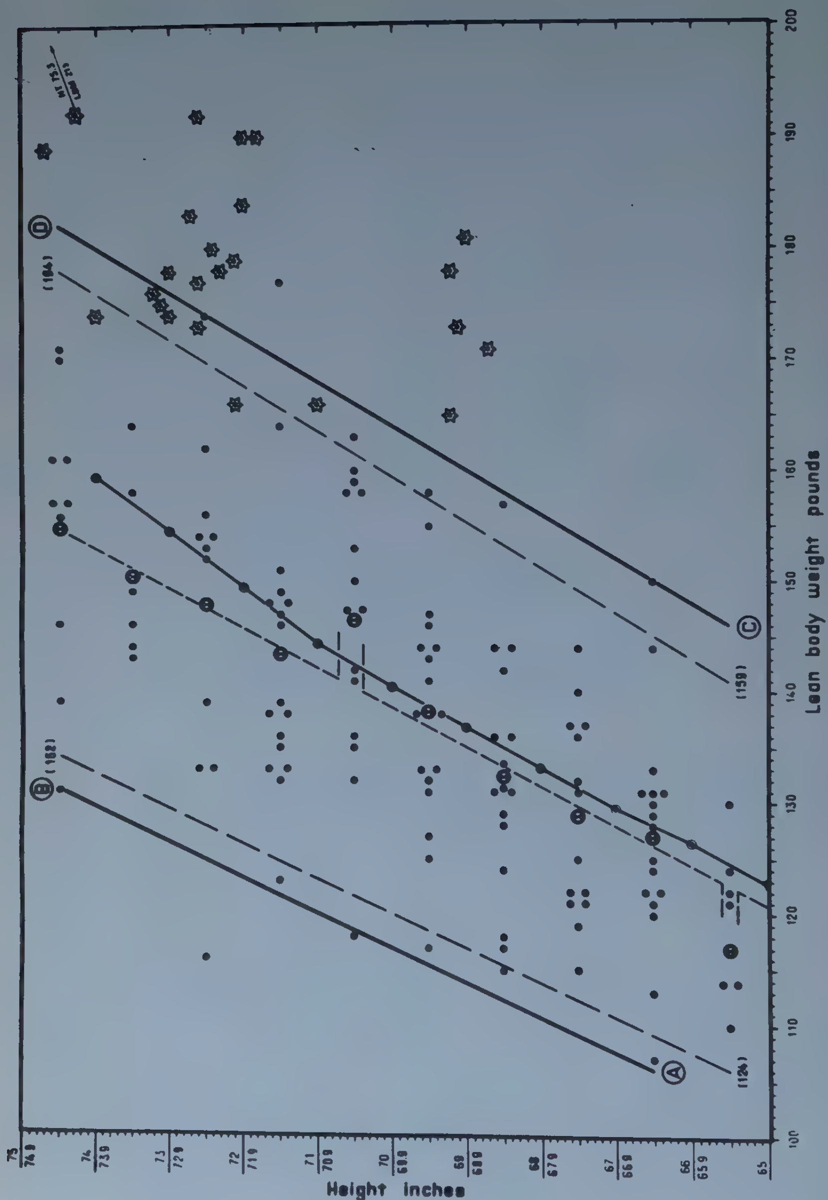

FIGURE 3 *(For description see facing page)*

also shows the estimates for mean LBW related to various statures pertaining to the general population and Army data. The regression equation of "SA" on LBW for these mean values is,

$$\text{LBW} = 47.1\ \text{“SA”} - 20.7.$$

Other equations derived from the individual data are similar and therefore have been omitted.

It should be noted for future reference that the ratio of surface area to LBW for women is some 10 per cent greater than the corresponding ratio for men of comparable H and LBW. This follows in part from the difference of 5 per cent in fat content postulated for men and women, and in part because of the smaller body size of women.

Basal (Standard) Metabolism

Boothby and Sandiford,[35] Berkson and Boothby,[8] Berkson and Dunn,[7] have analyzed part of their extensive data from the Mayo Clinic, and their conclusions are basic in this analysis:

a. The distribution of M approaches normality. In a group of normal men, ages 20 to 64 yrs., the coefficient of variation was $\pm$ 6.7 per cent.

b. The surface area (DuBois) formula gives a fair statistical measure of the amount of energy consuming tissue in the body, and normal metabolism is proportional to surface area.

c. Both the surface area and Harrison-Benedict formulas give about the best agreement between predicted and observed M that can be expected, considering the inherent variability of the observations.

In order to minimize the variability introduced by age, an independent analysis of data from (8) was made for a particular age group, 25 to 35 yrs. The coefficient of variation in these data was found to be $\pm$ 6.05 per cent of the mean.

Metabolic Level. There is about a 6 per cent difference between the values obtained by "clinical" and the laboratory determination of the "metabolic level", M/SA Cal $m^{-2}\ hr^{-1}$, age 25, of 40 and 37.5. There is also an age factor which will be considered below.

One of the advantages of the surface area formulation of M is that in this case M is written as the product of two factors, one the surface

FIGURE 3. *(See opposite page)* Individual LBW in relation to H, dots (Navy men) stars (athletes); mean values (Navy men) are designated by the large circles on or near the interrupted line. The estimated LBW values (.9 W) for the general male population[27] lie on the continuous central line.

A-B and C-D enclose more than 95 per cent of the Navy data; the adjacent interrupted lines, 124-152, and 159 and 194, (the numbers indicate W lb.) include 67 per cent of the gross weights of Army separatees.[28]

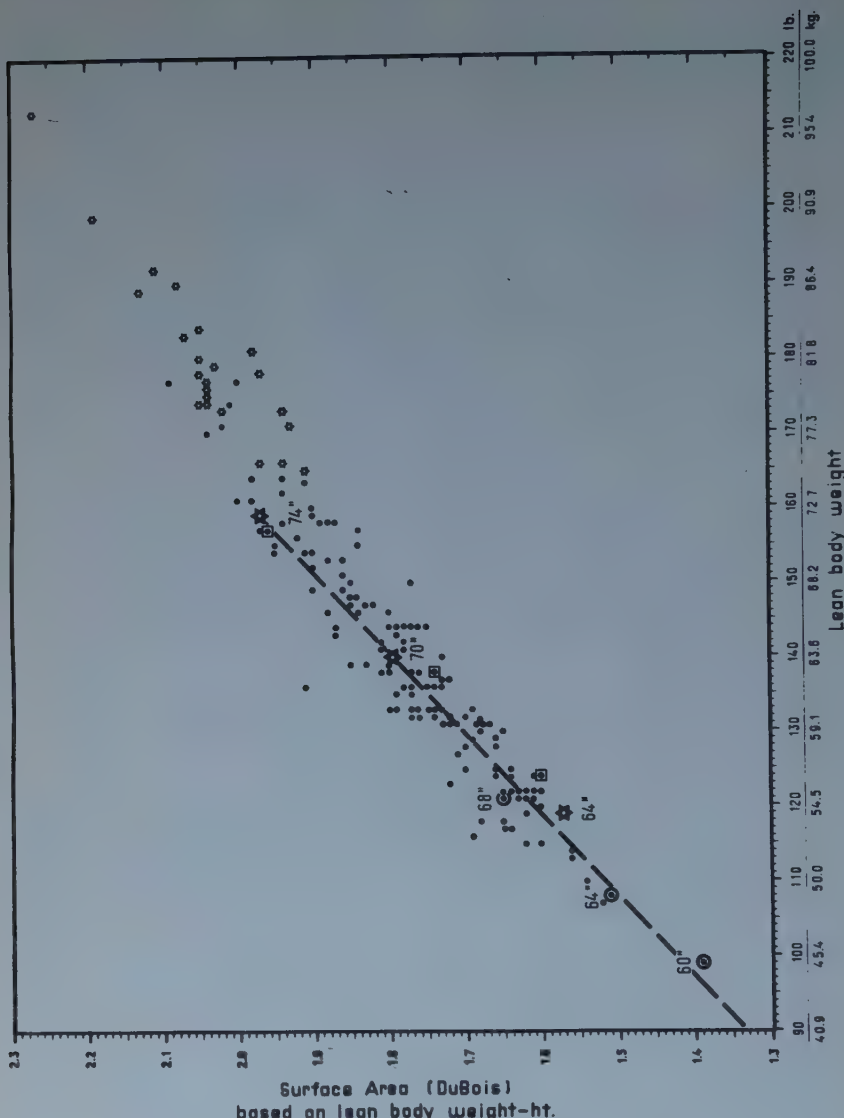

FIGURE 4 *(For description see facing page)*

area, independent of age and variables of technic, and the other, a factor incorporating age and the variables of technic.

Age and Metabolic Level. According to the Mayo standards (7) there is a decrease in unit metabolic rate of about 4 Cal m^{-2} hr^{-1}, or about 10 per cent between the ages 25 and 55. There exists some confusion, however, regarding the manner in which M varies with age. In passing from 25 to 55 yrs. of age, it appears that M actually falls off by about 5 per cent. If, in accordance with our postulate, the LBW remains constant, then we must conclude that over this period there is a true decrement of 5 per cent in M. Ordinarily, however, it is M/SA which is reported as a measure of metabolism. Due to the 10 per cent increase in excess fat, and therefore in W, the SA (which depends on W) increases by about 5 per cent over the same period. The quantity, M/SA, therefore, decreases by about 10 per cent between 25 and 55, and 10 per cent is then usually, but fallaciously, quoted as the decrement of M with age.

The data of Benedict[32] indicate wide variation in the falling off of M with age. Some individuals (weight constant) show little or no change; others, a progressive decrease. The age factor in the Harris and Benedict equations has been considered to be too high, especially for older ages. Lewis[33] found that for each decade between ages 40 and 89, there was a decrement of 0.664 Cal m^{-2} hr^{-1} (about 0.18 per cent decrease per year). The rate of decline in his subjects classified according to age grouping, was not smooth and even disappeared between 50 and 79 years (end of fattening?).

Removal of the Age Variable from the Metabolic Formulas and the Calculation of all M Values on the Basis of Age 25. It will greatly simplify our subsequent calculations if we treat the troublesome and conjectural age factor separately. From the data of Lewis and the analysis of the age factor in the preceding paragraphs, we may use a rounded figure of 0.2 per cent per year as a decrease in metabolism that occurs after age 25. The correction in any case is not large but still reservations apply which are obvious. Also a further comment may be made in that the correct manner of applying even a known age decrement to M awaits the results from such investigations as those which Brozek and Keys[30] and Shock[34] are pursuing. If the decline of M with age represents disuse atrophy[31] or possible alteration (sclerosis and fibrosis) and even loss of tissue, it will be necessary to adjust the

FIGURE 4. *(See opposite page)* LBW relative to surface area, dots (Navy men), small stars (athletes), r = .94 (approx.). The straight line passes through or adjacent to estimated general population LBW for women (circles, H, 60, 64, 68 in.) and for men (black stars[27] and squares[28], H, 74, 70, and 64 in.). If at age 25, LBW is .9 W (men) and .85 W (women), then the surface area/LBW ratio for women is about 10 per cent greater than the same ratio for men of *comparable* weights.

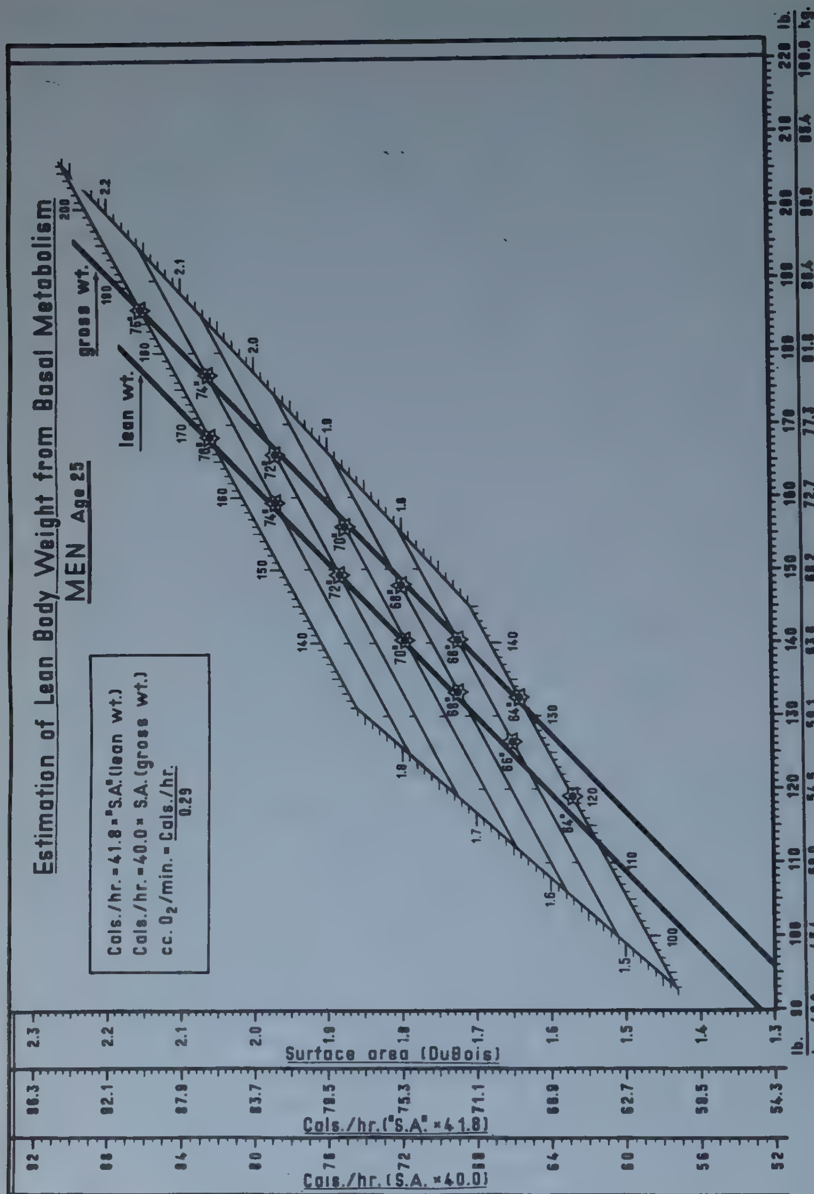

FIGURE 5 *(For description see opposite page)*

correction accordingly. Tentatively, we shall assume that no appreciable change in body composition takes place up to the age of 55. Between 25 and 55 yr. a mean decrement of about 6 per cent in M is assumed if 25 is the reference age in the formulas.

Formulas and Factors

It may be helpful at this time to record for future reference a number of formulations hereafter identifiable by the names of their authors:

Surface area (m^2 or cm^2) of man.

(DuBois, the reference standard), $W^{.425} \times H^{.725} \times 71.84$

("DuBois"), $W^{.5} \times H^{.5} \times 167.1$

(Boyd)

a. biparameter, $3.207 \times W_{gm.}^{.7285 - .0188 \log. W gm.} \times H^{.3}$

b. monoparameter, $4.688 \times W_{gm.}^{.8168 - .0154 \log. W gm.}$

(Brody), $W^{.53} \times H^{.4} \times 240$

Metabolism (Cal hr^{-1}). For the mean of any species:

(Kleiber), $\dfrac{70\ W^{.75}}{24}$

(Brody), $\dfrac{70.5\ W^{.73}}{24}$

(Hemmingsen, from Kleiber, Brody, Krogh and others),

$\log \text{Cals.} = -1.67 + .73 \log W\text{gm.}$

or $3.311\ W^{.73}$

For various human individuals, M predicted from SA multiplied by a factor for Cal $m^{-2}\ hr^{-1}$ (Boothby, Berkson, and Dunn,[7] or Aub and DuBois[40]):

men, $66.473 + 13.7516\ W + 5.0033\ H - 6.755$ age yr.

women, $655.0955 + 9.5634\ W + 1.8496\ H - 4.675$ age yr.

(Harris and Benedict)

FIGURE 5. *(See opposite page)* A linear plot based on the following, Cal $hr^{-1} = .55\ W + .2\ H \approx$ SA (DuBois) $\times$ 40. The heavy oblique lines are drawn through mean W for men, age 27 and through estimated LBW (.9 W). The parallel transecting lines at each stature level traverse a distance of ± 2 SD from the mean LBW. The respective ordinate scales for W and LBW are, SA $\times$ 40 Cal $m^{-2}\ hr^{-1}$, and "SA" $\times$ 41.8 Cal $m^{-2}\ hr^{-1}$. From the observed metabolism for a given individual, W or LBW, depending upon the ordinate scale used, can be read as the coordinate point on the stature line designated by the individual's height. Equivalent SA values (DuBois) can also be estimated. For ages over 25, a correction factor discussed in the text is applied.

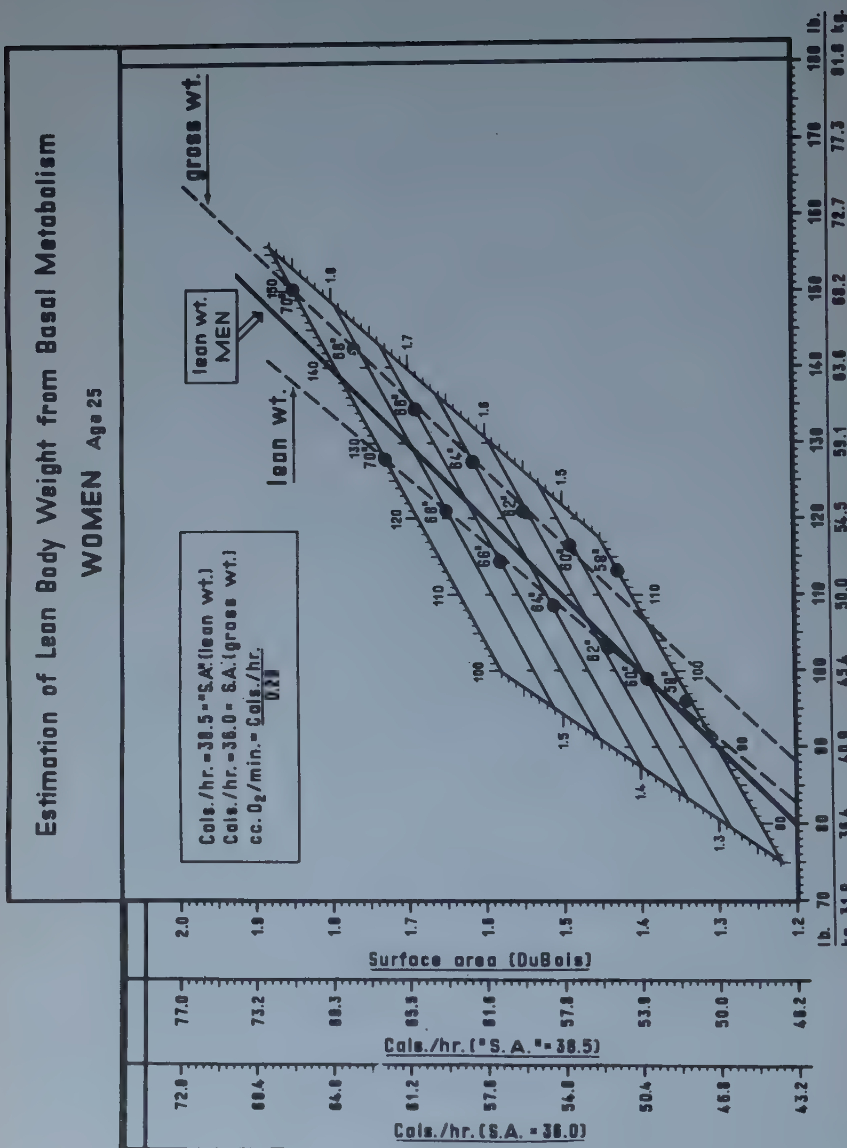

FIGURE 6 *(For description see facing page)*

Conversion Factors. 4.83 Cals., is used as the Caloric equivalent of 1 liter of oxygen, R.Q., approximately, .83.

$$\frac{\text{Cals./24 hr.}}{6.96} = \text{cc } O_2\text{/min.}$$

$$\frac{\text{Cals./hr}}{.29} = \text{cc } O_2\text{/min.}$$

$$1.17 \text{ Cals./kg.LBW} = 4.02 \text{ cc } O_2\text{/min./kg.LBW.}$$

Estimation of Metabolism, and from it, Individual Lean Body Weight, Given Age, Height, and Weight

Linear Representation of Data, FIGURES 5, 6. In the preceding paragraphs the relationships between LBW and W, LBW and SA, and SA and M, have been outlined. It is now possible to relate LBW and M, using at first values of M calculated from age, H, and W. As "working units" for the calculation of M, it is convenient to employ the familiar gross weights for age 25(TABLE 2) and to consider that LBW is a constant fraction of W (.9 W for men, LBW index 2.04, and .85 W for women, LBW index, 1.87).

It is also convenient to present the calculations in linear form; a simple linear approximation to the DuBois formula is,

$$SA = \frac{.55\text{ W} + .2\text{ H},}{40} \quad \text{or} \quad \frac{.25\text{ W lb.} + .508\text{ H in.}}{40}$$

For men age 25

$M = .55\text{ W} + .2\text{ H}$; "clinical" metabolic level $= 40\text{ Cal m}^{-2}\text{ hr}^{-1}$

For women age 25

$M = .9\,(.55\text{ W} + .2\text{ H})$, "clinical" metabolic level $= 36\text{ Cal m}^{-2}\text{ hr}^{-1}$

Values derived from these formulas are plotted in FIGURES 5 and 6.

In terms of LBW these formulas become,

FIGURE 6. *(See opposite page)* It corresponds to FIGURE 5 and is a linear plot based on the following,

$$\text{Cal hr}^{-1} = .9\,(.55\text{ W} + .2\text{ H}) \approx \text{SA (Du Bois)} \times 36$$

The interrupted oblique lines are drawn through mean W for women, age 25 (27) and through estimated LBW (.85 W). The parallel transecting lines traverse a distance of 2 SD on either side of the mean LBW. The respective ordinate scales for W and LBW are, SA × 36 Cal m^{-2} hr^{-1}, and "SA" × 38.5 Cal m^{-2} hr^{-1}, W or LBW are obtained from observed metabolism as in FIGURE 5.

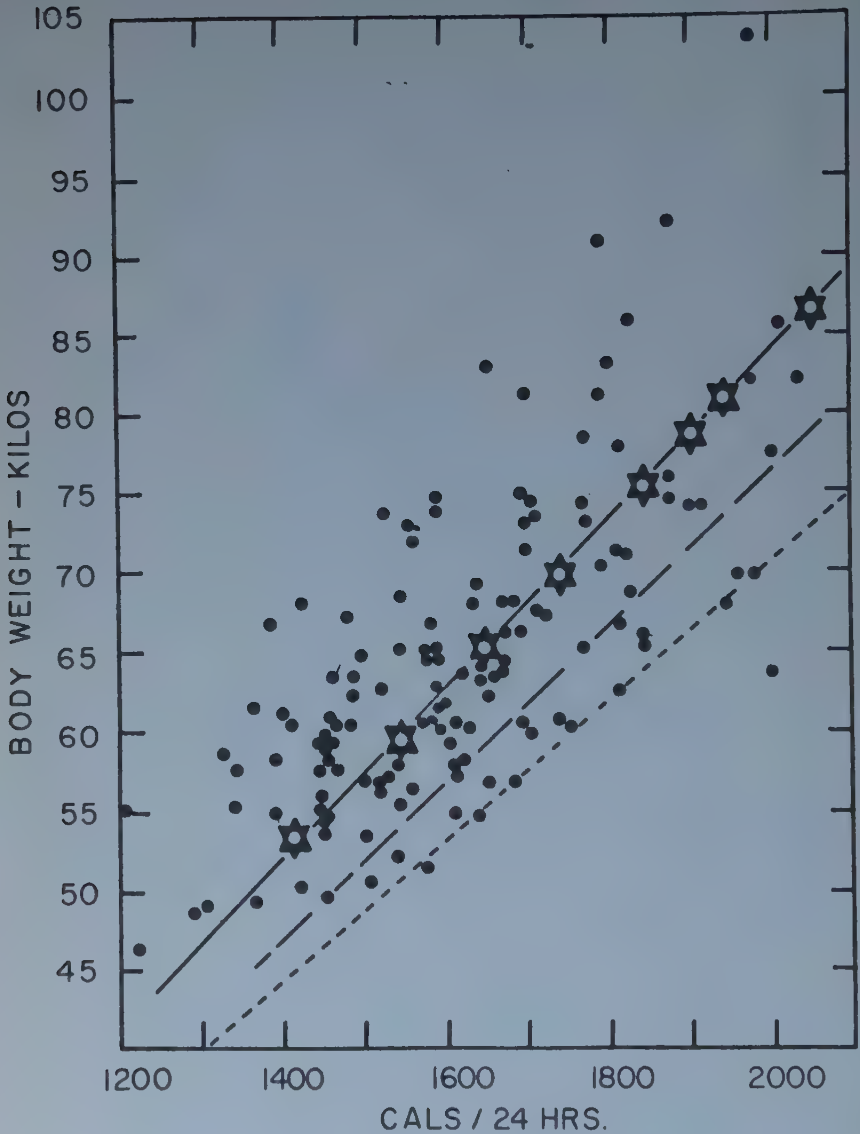

FIGURE 7 *(For description see facing page)*

$$\text{LBW (men)} = \frac{\text{Cal hr}^{-1} - .2\text{ H}}{.6165}, \text{ and}$$

(The denominator, .6165, becomes .6, if the metabolic level = 39.4 Cal $m^{-2}hr^{-1}$)

$$\text{LBW (women)} = \frac{\text{Cal hr}^{-1} - 1.8\text{ H}}{.5847},$$

(The denominator, .5847, becomes .582 if the metabolic level = 35.5 Cal $m^{-2}hr^{-1}$)

The value of the denominator in each equation is adjusted to the metabolic level and the age correction factor is applied to this value, *e.g.*, at age 55, it would be decreased by 16.6 per cent (men) relative to the 6 per cent caloric decrease, ages 25 to 55.

Compilation of Formulas for the Estimation of LBW from M. Although the formulas of the previous section are fundamental and accurate, simpler formulas applying to special cases, or giving rougher estimates, are frequently convenient. We now proceed to compile some of these.

a. For an individual whose H and W are the means of the general population, or as a rough approximation for any individual, whether man or woman, LBW $= \frac{\text{Cal hr}^{-1}}{k}$, where k = 1.175 Cal hr^{-1} kg^{-1}.

b. For individuals of the general population who have no fat, the mean LBW = 47.1 "SA" − 20.7.

For individuals of the general population, aged 25, and having average amounts of fat, the mean

$$\text{LBW} = 45\text{ SA} - 20.7, \text{ (men)}$$

$$\text{LBW} = 44\text{ SA} - 20.7, \text{ (women)}$$

In terms of M.

$$\text{LBW} = 1.125\text{ Cal hr}^{-1} - 20.7, \text{ (men; age 25; metabolic level, } 40\text{ Cal m}^{-2}\text{ hr}^{-1}\text{)},$$

or

$$\text{LBW} = 1.125\text{ Cal hr}^{-1} - 20, \text{ (metabolic level, } 39.5\text{ Cal m}^{-2}\text{ hr}^{-1}\text{)}$$

This last formula is the linear approximation to,

$$\text{Cal hr}^{-1} = 3.311\text{ W}^{.73}, \text{ where LBW is .9 W.}$$

Corresponding to the first equation, for men,

$$\text{LBW} = 1.222\text{ Cal hr}^{-1} - 20.7, \text{ (women; metabolic level, } 36\text{ Cal m}^{-2}\text{ hr}^{-1}\text{)}$$

FIGURE 7. *(See opposite page)* It is a mirror image reproduction in order to exchange coordinates, of Benedict's FIGURE 12 (1). The individual values are for men, ages 20 to 60 yrs. The two interrupted lines have been introduced by this author to approximate a "zero per cent fat line", *i.e.*, a line drawn through the highest metabolism values relative to W. The stars were also drawn in and represent mean male weights corresponding to statures of 61 to 77 in. (the general population curve for men, age 25). The ordinate (M) values corresponding to these weights and statures were predicted from the Harris-Benedict formula. Individual values lying between the interrupted lines are almost without exception abnormally high according to the prediction of the H-B formula. Corrected, these points lie on or above the upper inserted line. This, then, is the probable base line ("0" % fat) and the mean fat content of Benedict's subjects was about 10 per cent. Also LBW = .9 W and the W values lie on or close to the general trend curve.

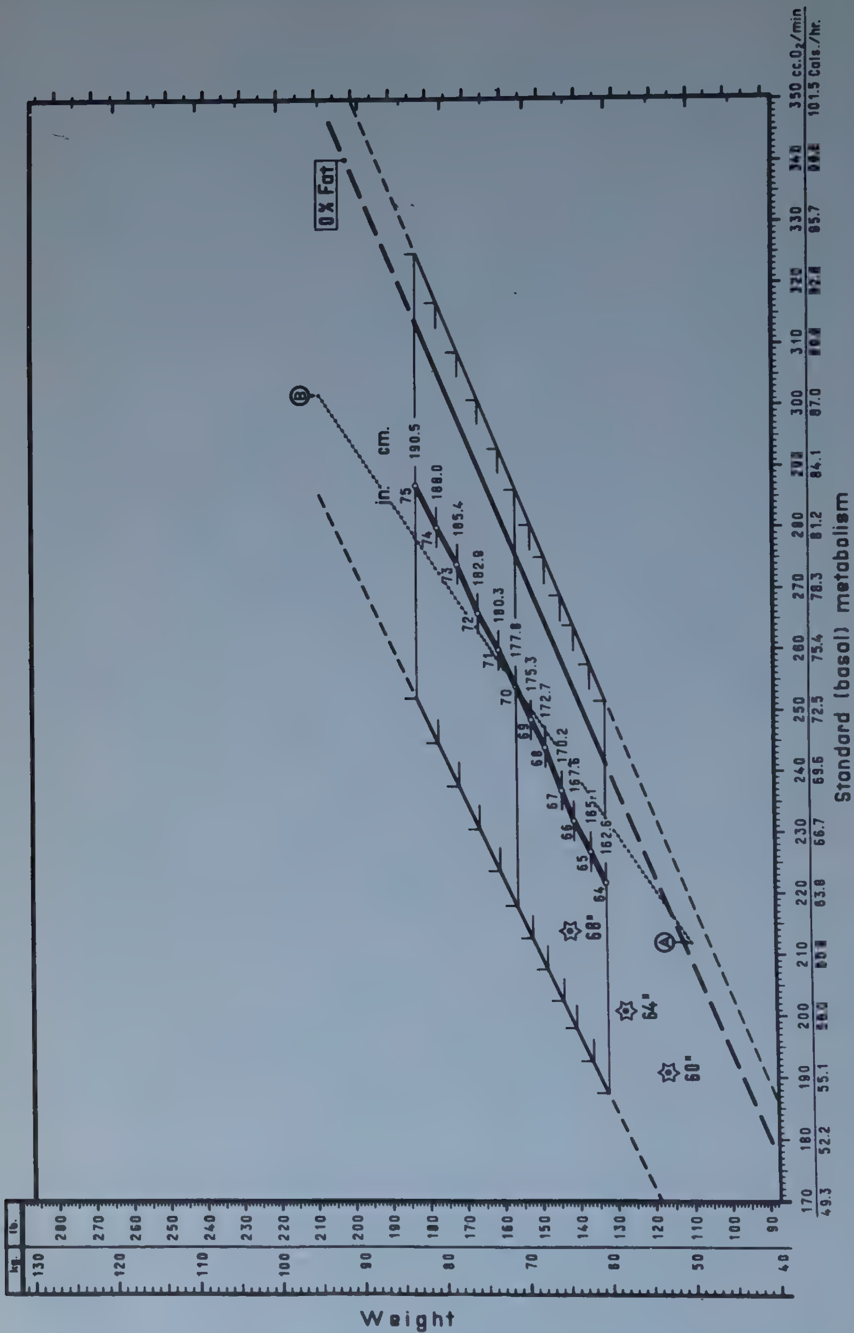

FIGURE 8 *(For description see facing page)*

Estimation of Lean Body Weight from Metabolic Data of Benedict et al.

Benedict's Data Plotted in Relation to Gross Weight. Turning now from M *calculated* from age, H, and W, to *measured* values of M, we proceed to analyze the classical data of Benedict *et al.*,[1,38,39] and to compute LBW from these data. For graphical convenience, the co-ordinates on the original Benedict plot[1, FIG. 12] have been interchanged (by mirror reflection); See FIGURE 7., where below Benedict's general tendency line, I have added a finely broken line whose slope must approximate the ratio, LBW/M, since individuals whose points lie above this line must exhibit excess fat, decrease of metabolism with age, or individual variations related to stature. With one or two exceptions, however, the metabolisms of individuals whose points lie on this line are as much as 10 per cent above "normal", by the Harris-Benedict standard. If the metabolisms of these points are shifted left-ward by the appropriate correction (keeping weights constant), the points lie on or above the coarsely divided line. We may tentatively assume that the slope of the coarsely divided line actually gives LBW/M. If this be true, then the general tendency (heavy) line is characteristic of individuals having about 10 per cent excess fat. This hypothesis may be tested using, not Benedict's data,but the data for the general male population, age 25 (TABLE 2). We may choose certain statures, starting with 61 in. and going to 77 in., find (from the table) the corresponding mean weights, and substitute these into the Harris-Benedict equation to obtain M's. These computations locate (FIGURE 7) the stars, which obviously fit on the line of general tendency for Benedict's subjects. But in the earlier portion of this paper we have shown that for our general population, LBW = .9 W.

Graph for the Estimation of LBW from Metabolism Based on the Data Computed by Means of Harris-Benedict Equations, FIGURE 8. Predicted metabolic rates are shown for Standard Table mean weights (men, age 25) relative to statures of 64 to 75 in. For women, similar values are recorded for statures of 60, 64, 68 in.

The ordinate values are 90 per cent of general population male mean gross weights, age 25. The horizontal lines crossing each increment of stature represent about + 2 S.D. of metabolism from the man.

FIGURE 8. *(See opposite page)* The general population M and W data (men, age 25) have in effect been transferred from FIGURE 7, and for comparison three similar values (stars) have been introduced for women of statures 60, 64, and 68 in. The "0" per cent fat base line is also in the same relative position as in the preceding figure. Mean lean body weights (.9 W on the heavy line) relative to stature can be read from this base line projected to the ordinate scale. A-B and lines parallel to A-B at each stature level indicate the "subtle" correction for height. LBW is computed as 90 per cent of the ordinate values corresponding to points on A-B or the parallels passing through the various increments of stature on the mean W line.

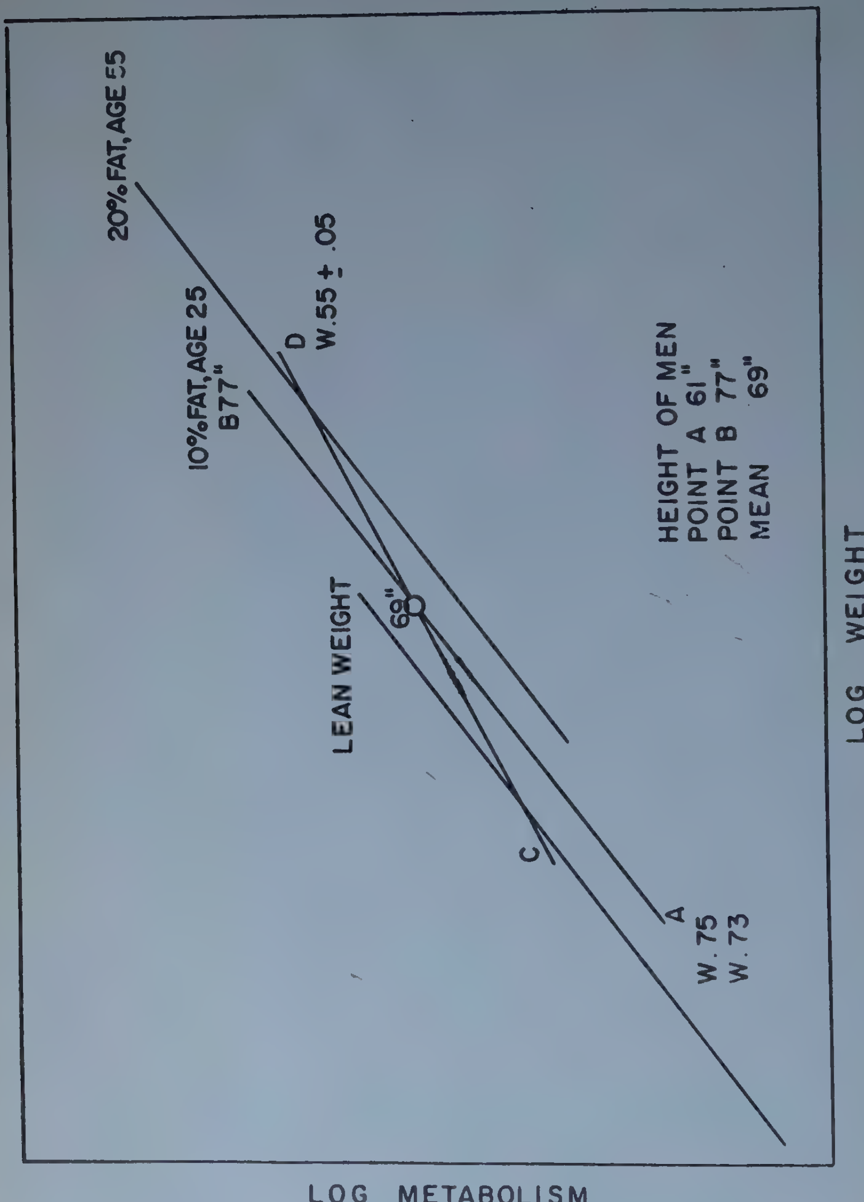

FIGURE 9 *(For description see facing page)*

For ages over 25, the age correction factor (page 1113) is applied to the metabolism values along the abscissa.

The "0" per cent line gives an approximation of LBW relative to metabolism for general population mean weights relative to changing stature. For weights along a constant stature line, it is necessary to apply a "subtle" (Benedict) correction for stature. This is indicated by the deviation of the line A-B from the general population curve at a stature level of 70 in. For statures other than 70 in. the lines (not drawn in) run parallel to A-B. The coordinate values for points on any stature line are in terms of metabolic rate and weight (10 per cent fat). Thus a metabolic rate of 74.2 Cal hr^{-1}, or 256 cc O_2/min. (R.Q., 0.83) for an individual 70 in. tall corresponds to a weight of 156 lb. on the ordinate scale. The corresponding LBW is 90 per cent of this value or 140.4 lb. If the metabolic rate were 81.2 Cal hr^{-1} or 280 cc O_2/min., the corresponding weight value on the ordinate scale would be 185.5 lb. and the LBW, 167 lb.

II. *BASIC CONSIDERATIONS AND DATA*

Surface Area and Metabolism

The various formulas for the estimation of surface area and the prediction of M are applied essentially to two distinct conditions represented by,

a. the general population mean height-weight data in Table 2 (Curve AB, Figure 9).
b. individuals of a given height, whose weights are dispersed about the mean weight (Curve CD, Figure 9).

Both mono- and biparameter equations in terms of height and weight apply to (a) and there can be great latitude in the range of values for the regression coefficients (linear formulas) or exponents (power equations) for W and H. But to (b) only the biparameter equations (the "bidimensional" principle of DuBois) apply, and the regression coefficients or exponents for W and H are restricted to narrow limits, unless loose approximations are acceptable.

As a "working unit" (because formulas were developed by DuBois, Harris and Benedict, and others to predict M on the basis of W and not

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Figure 9. *(See opposite page)* For points on the general population curve (AB), *i.e.*, mean W relative to increments of stature, M is related to approximately $W^{.75}$, and specifically for AB,

$$M = 3.311\ W^{.73}\ .$$

Varying the percentage of fat alters the coefficient of W but not the power.

When W changes in relation to constant stature as along CD, then M is proportional to $W^{.55}$ and a "bidimensional" expression is required as, $M = k\ W^{.55} \times H^{.4}$

LBW) we shall continue to use W, but with the qualification that the constant percentages of fat for men and women, age 25, be maintained. It will be apparent from the data to be presented that accurate predictions cannot be made from the formulas when the fat percentages of body weight differ appreciably from those of the general population, *i.e.*, a population in which there is an increase in fat from 10 to 20 per cent between ages 25 and 55, to which the various formulas have been adjusted empirically.

a. *Surface Area in Relation to Height-Weight Values of the General Population Curve.* Mean weights (TABLE 2), and corresponding statures whose range is nearly ± 3 S.D from the mean, were selected for comparison of various surface area formulations which include either or both height and weight parameters incorporated in linear and power equations (TABLE 4).

Of special interest is the fact that surface area is proportional to a fractional power of body weight, not $W^{.67}$ (the "surface area law") but to kW^n, where n is approximately .75,

$$\text{or, S.A.} = kW^{.75}$$

It is also proportional to a power of height for the same data,

$$\text{or, S.A.} = kH^{1.5}$$

In a biparameter equation such as $SA = kW^a H^b$, where also, $H = hW^c$, any combination of exponents, a and b, may be used, provided that $a + bc = .75$. For instance, if as given in an earlier section, $c = .5$,

$$\text{S.A. (DuBois)} = kW^{.425} \times (H^{.725})^{.5} = kW^{.787}$$

$$\text{S.A. (Brody)} = kW^{.53} \times (H^{.4})^{.5} = kW^{.73}$$

$$\text{S.A. ("DuBois")} = kW^{.5} \times (H^{.5})^{.5} = kW^{.75}$$

Hemmingsen's interspecific equation will be altered only to introduce a divisor, 40, *i.e.*, a representative value for Cal m^{-2}, for men, age 25, thus,

$$\text{S.A.} = \frac{3.311\ W^{.73}}{40}$$

b. *Surface Area and Weight, Height Constant, Curve CD,* FIGURE 9. For any given stature,

$$\text{S.A.} = kW^{.55 \pm .05}$$

For all adult weights and statures, we have, from the "bidimensional" principle of DuBois, the following approximation,

$$\text{S.A} = kW^{.55 \pm .05} \times H^{.4 \pm .1}$$

The derivation of the exponents for W and H will be outlined in a following paragraph dealing with metabolism formulas.

c. *Surface Areas for Mean Weights and Statures Associated with the Male Growth Curve, Ages 1 to 20.* If the constant in the Hemmingsen's equation is altered from 3.311 to 3.484, then predicted surface area values for mean weights and statures associated with growth from

TABLE 4

COMPARISON OF FORMULAS FOR THE ESTIMATION OF SURFACE AREA FOR MEAN WEIGHTS RELATIVE TO STATURE ON THE GENERAL POPULATION H-W CURVE FOR MEN, AGE 25.

Formula	H 154.9 (61 in.) / W 54.4 (119.7 lb.)	H 175.3 (69 in.) / W 69.6 (153.1 lb.)	H 195.5 (77 in.) / W 86.6 (190.5 lb.)
	surface area, sq.m.		
Biparameter equations*			
a. power type			
DuBois	1.520	1.842	2.192
Boyd (W, H)	1.547	1.861	2.193
$228.5\ W^{.55} \times H^{.4}$**	1.547	1.860	2.179
b. linear			
$\frac{.55\ W + .2\ H}{40}$	1.522	1.832	2.168
Monoparameter equations***			
a. power type			
From Hemmingsen, Brody			
$\frac{3.311\ W^{.73}}{40}$	1.532	1.829	2.150
From Kleiber			
$\frac{3.07\ W^{.75}}{40}$	1.537	1.850	2.174
Boyd (W)	1.554	1.847	2.149
b. linear			
$\frac{.8064\ W + 17.18}{40}$	1.542	1.833	2.175
$\frac{.629\ H - 36.85}{40}$	1.515	1.835	2.153

* Applicable to all values for H and W (except (b) for ages under 8) i.e., rigidly applicable when W/v = k (densimetric equivalence)

** Essentially Brody's equation

*** Applicable only to mean W relative to H or H relative to mean W.

infancy to adulthood, are in close agreement with values predicted from the DuBois and Boyd equations (TABLE 5). On the other hand, the limitations of a linear formulation, *e.g.*, $\frac{.55\ W + .2\ H}{40}$, are apparent from

the data in this table, *i.e.*, the surface area predictions for ages 1 through 6 may be divergent by as much as 10 per cent.

The following generalizations summarize the substance of the preceding paragraphs,

TABLE 5

COMPARISON OF FORMULAS FOR THE ESTIMATION OF MEAN SURFACE AREAS FROM MEAN WEIGHTS AND STATURES PERTAINING TO CONSECUTIVE AGES DURING THE MALE GROWTH PERIOD.

Age yr.	H* cm.	W* kg.	Surface area m^{-2}				
			Formula				
			(1)	(2)	(3)	(4)	(5)
1	73.7	9.55	.433	.452	.499	.451	.442
2	83.8	11.8	.509	.528	.581	.547	.522
3	91.4	13.8	.579	.592	.647	.614	.589
4	99.1	15.9	.667	.656	.712	.682	.658
5	106.7	16.7	.702	.687	.763	.701	.696
6	115.0	19.5	.790	.760	.842	.802	.774
7	120.0	22.7	.883	.851	.912	.884	.858
8	125.0	25.0	.935	.935	.970	.947	.919
9	130.0	27.7	1.005	.984	1.030	1.013	.988
10	135.0	30.4	1.074	1.053	1.092	1.077	1.055
11	140.0	34.0	1.155	1.143	1.167	1.162	1.139
12	145.0	36.8	1.230	1.211	1.231	1.231	1.220
13	150.0	40.9	1.315	1.308	1.312	1.316	1.305
14	157.5	46.8	1.443	1.443	1.431	—	—
15	162.6	50.8	1.530	1.532	1.514	1.518	1.519
16	167.6	57.3	1.649	1.673	1.625	—	—
17	170.2	60.4	1.702	1.738	1.681	—	—
18	172.7	62.7	1.748	1.787	1.725	1.735	1.737
20	175.3	63.2	1.774	1.797	1.745	1.750	1.766

*H, W data relative to age from Talbot,[57] Lewis, Kinsman, and Iliff,[58] and Barach.[59]

(1) DuBois, (2) From Hemmingsen, Brody, $\frac{3.484\ W^{.73}}{40}$

(3) $\frac{.55\ W + .2H}{40}$, (4) Boyd (H, W), (5) $228.5\ W^{.55} \times H^{.4}$

1. Throughout the range of adult statures the mean surface area is proportional to a fractional power of the corresponding mean weights, of the order of 0.73.

2. For any given stature the surface area is proportional to a fractional power of weight of the order of 0.55.

3. During the growth period from infancy onward the mean surface area at any given age is proportional to a fractional power of mean weight associated with that age, of the order of 0.73.

Metabolism Formulas

Slope of M-W Curve, Given H (Curve CD, FIGURE 9), *and the Equation,* $M = 228.5\ W^{.55}\ H^{.40} \times$ *Cal* $m^{-2}\ hr^{-1}$. As already mentioned, M appears to be normally distributed in the general population. Jerome,[40] analyzing the data of Boothby, Berkson, and Dunn[7] in the age range, 25-35, found the coefficient of variation of M to be ± 6 per cent. The coefficient of variation of LBW (also normally distributed) among Navy men is ± 10.9 per cent. Assuming that these two functions meet the requirements on page 1101, it follows that 6/10.9 = .55 is the exponent in the power equation relating M to LBW, *i.e.*,

$$M = k'\ (LBW)^{.55},\ H,\ \text{constant}.$$

Analogous relationships can be expected between M and total body water (20), thiocyanate space (21), etc. To extend this equation to cases of variable H, we have to recall that $W = hH^2$, and that if M is expressed totally in terms of W the exponent of W must be of the order of .75. From these facts and the condition discussed on page 1121, it follows that the exponent of H must be .4, *i.e.*,

$$M = k\ W^{.55}\ H^{.40}$$

These exponents, of course, are only approximations, since the coefficient of variation of M may vary from 5 to 7, and that of LBW from 9 to 13; their quotient may lie between .5 and .6. If we wish to develop the formula for the SA factor of M, we can find the numerical value of k from the knowledge that an area of 1.86 m^2 corresponds to a height of 175.3 cm (69 in.) and weight of 69.6 kg (TABLE 4).

This equation is essentially the same as one developed by Brody,[3] using an ingenious graphical method; it is presented here solely to illustrate its underlying principles. According to DuBois and DuBois[5] their similar equation (in which both W and H have the exponent, .5) did not fit their data as well as their "standard formula"; actually, it differs appreciably from the equations above only when extreme limits of W and M are tested.

The Formulas, Cal $hr^{-1} = .55\ W + .2\ H$ *(men, age 25), and* $SA = \frac{.55\ W + .2\ H}{40}$, are perhaps something more than "skeletonized" Harris and Benedict equations. Berkson and Boothby[8] previously pointed out that SA could be derived from the Harris-Benedict linear formulation. Several comments, however, are appropriate. The age factor has been removed because it was believed that it could be treated best separately. The value of .55 as the regression coefficient of W gave the closest approximation to the metabolic data for both men and women. A mean value of .575 (range .54 to .59) was obtained for the formula applicable to men.

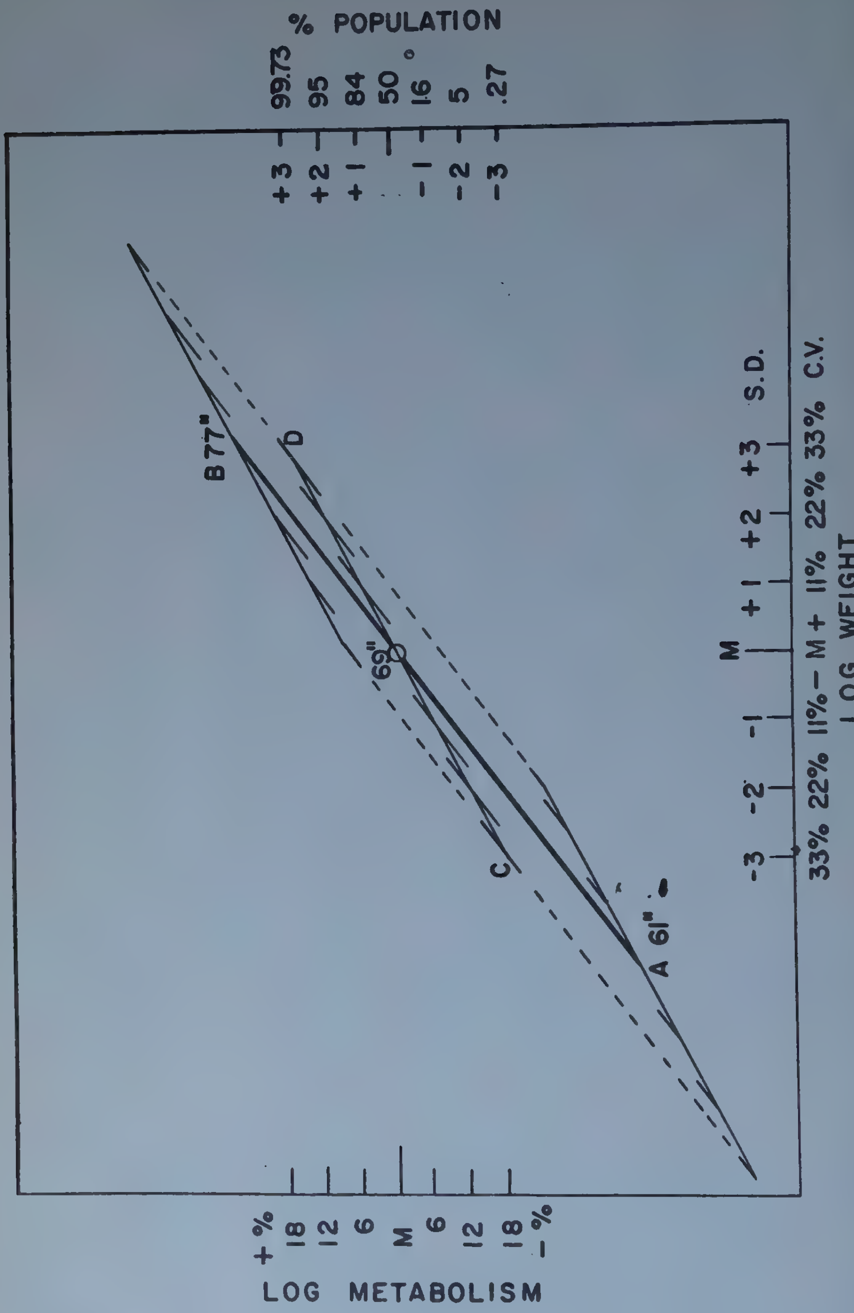

FIGURE 10 *(For description see facing page)*

The multiple, .9, introduced for the prediction of the metabolism of women, *i.e.*, M = .9(.55 + .2H), follows ostensibly from $M = \frac{.55\,W + .2\,H}{40} \times 36$ *i.e.*, SA × Cal m^{-2} hr^{-1}, but basically from $\frac{SA}{LBW}$ ratio which in women is about 10 per cent greater than for men of comparable weight (FIGURE 4). A 10 per cent reduction in the Cal m^{-2} hr^{-1} factor for women results in equality of M per unit of LBW for men and women.

The Hemmingsen Interspecies Equation Derived from Data of Kleiber, Brody, Krogh, and Others, log Cal hr^{-1} = –1.67 + .73 log W gm. This equation may be put into the following form,

$$\text{Cal hr}^{-1} = 3.311\ W_{\text{kg}}^{.73}.$$

This formulation describes the metabolism of various species which range in weight from .1 mg. to several thousand kg. As pointed out previously, a divisor of 40 introduced into this equation converts it into one which predicts accurately, *within* the human species, surface area from mean W on the general population curve (AB, FIGURE 9), and from mean W relative to age during the growth period (TABLE 5). Unaltered, it states M for men, age 25, whose weights lie in the general population curve. It may be fortuitous that the mean weight data of the Standard tables, *i.e.*, for age 25, fit so well in the formula as it stands. However, the position in space only of the logarithmic curve and not the slope, is changed when the coefficient of W is altered as it would have to be for mean weights other than those used.

Metabolism and Weight in Terms of Fractions or Multiples of their Standard Deviations and Coefficients of Variation. On the basis that M and W values are distributed normally, then without reference to formulas, one can calculate from mean values and coefficients of variation, all of the values which correspond on the respective distribution curves (FIGURE 10). In TABLES 6 and 7, extreme values of W, ± 3 S.D. (± 33% from the mean) relative to extremes of stature (about ± 3 S.D.), are tabulated with their corresponding metabolic values, *i.e.*, also ± 3 S.D. (± 18% from the mean).

In TABLES 6 and 7, these values in deviation form are compared with values predicted by means of several formulas. The agreement between the data so obtained is exceptionally good when one considers the extreme range of value employed. It is observed, however, that there is a real difference between weight exponent .425 in the DuBois formula, and weight exponent .55 or higher in the other equations.

FIGURE 10. *(See opposite page)* AB is the general population and CD the specific stature line as in FIGURE 8. The relationship of metabolism to weight (W) and LBW can be stated in terms of fractions or multiples of SD units or the percentages (coefficients of variation) which correspond to these units. Along CD the weight deviations from the mean are shown in relation to the corresponding deviations of M from the mean. The percentage of the population included within given ranges of deviation is shown by the scale on the right.

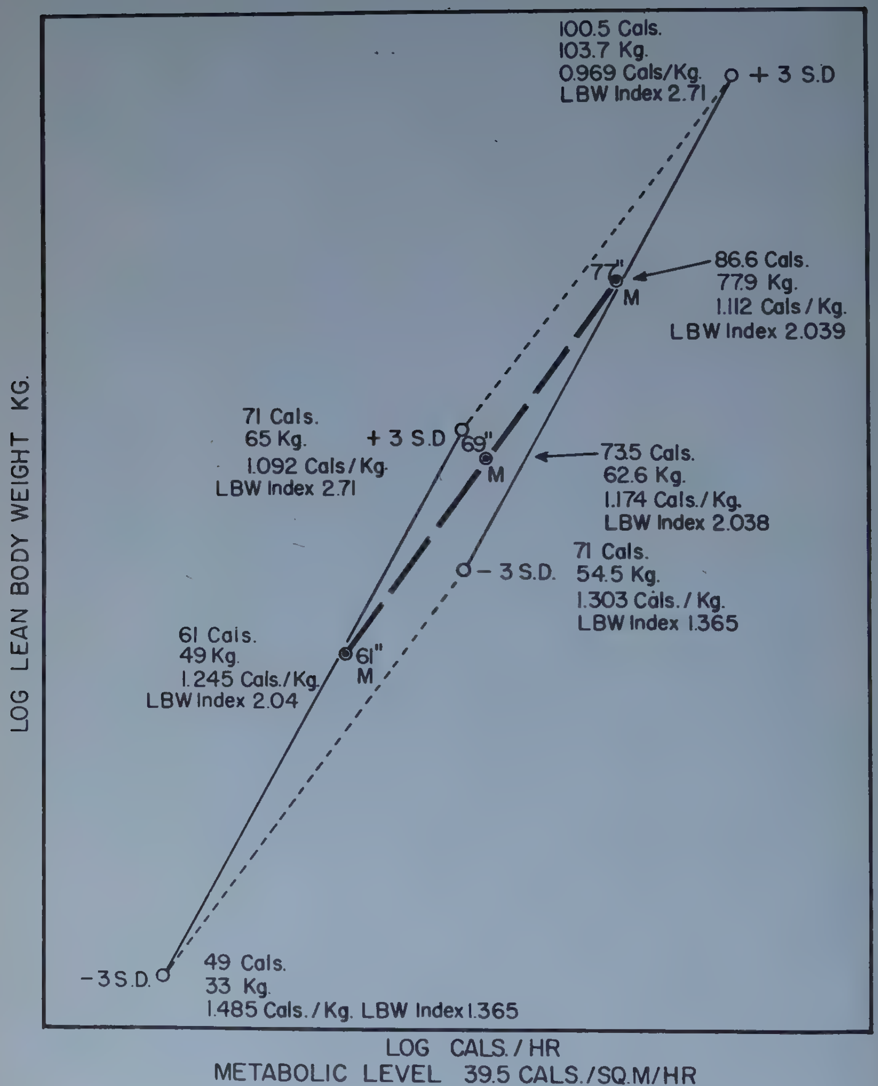

FIGURE 11 *(For description see facing page)*

That the exponent, .425, is too low, is suggested by the application of the DuBois formula to estimate the area of a cylinder. In the case of a long cylinder the ratio of surface area to volume calculated from the formula is larger than a similar ratio for a cylinder of the same diameter but half the length. This is not dimensionally correct.

The limitations of predicting M from W alone, *i.e.*, $kW^{.73}$, are also evident in the differences as large as 10 per cent between values predicted from this equation and the biparameter formulas.

In FIGURE 11 one observes the extreme range of possible LBW and metabolism values based on the data in TABLE 6, *i.e.*, an increase in LBW from some 33 to 103 kg. and M from 50 to about 100 Cal hr^{-1}. Of special interest is the fifty per cent difference in M per unit of LBW corresponding to the extreme differences in individual size. The appropriateness of the LBW index for comparing individuals of different stature is also evident.

Comparison of Specific Metabolism for (M/LBW) for Men and Women

The metabolism of women per m^{-2} of surface area is at least 10 per cent lower than that for men (35.5 or 36 Cal m^{-2} hr^{-1} compared with 39.5 or 40). If their surface area is 10 per cent greater per unit of LBW, then for men and women of comparable weights and statures, the respective Caloric values per kilogram LBW should be similar. The tabular data confirm this prediction (TABLE 8). In part this similitude is brought about by the assignment of a value of 15 per cent of total weight as fat compared with 10, for men age 25. Were the fat percentages the same, however, the surface area (LBW) ratio for women would still be about 5 per cent higher than a similar ratio for men.

Some data bearing on the sex difference in fat content may be outlined. In the guinea pig which is closely comparable in LBM and fat content to man, it was observed by Rathbun and Pace[13] that the mean fat percentage of gross female weights was 14.5 compared with 9.8 for the male.

Measurements of skin folds by experienced personnel provide reasonably good mean approximations of body fat. Edwards[29] reported that the mean of 53 skin fold thicknesses in women (H, 64 in., W, 121 lb., age groups 20 to 24 yrs.) was 640 mm. In men (H, 67.8 in., W, 146.1 lb.,

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FIGURE 11. *(See opposite page)* In the LBW-M parallelogram the range of normal values are shown for extremes of stature (LBW $\pm$ 3 SD for statures of 61 and 77 inches). The variation in M is 49 to 100.5 Cal and for LBW, 33 to 103.7 kg. The ratio, $\frac{\text{Cal hr}^{-1}}{\text{LBW}}$, has a low value of 0.969, and a high value of 1.485. The LBW index, $\frac{\text{LBW gm.}}{\text{H}^2\text{ cm.}}$, remains constant for comparable positions on the parallelogram.

TABLE 6

CALORIES PER HOUR FOR MEN, AGE 25, PREDICTED FROM FORMULAS AND FROM THE POSITION ON THEIR RESPECTIVE DISTRIBUTION CURVES OF VALUES FOR W AND CALORIES, EXPRESSED IN S.D. UNITS. COEFFICIENTS OF VARIATION, W, ± 11%, CAL, ± 6%. VALUES FOR W (10% FAT) ARE FROM TABLE 2, (COL. 2). THE RANGE OF STATURE IS NEARLY ± 3 S.D.

Formula	W		W mean		W
			H 154.9 cm. (61 in.)		
	36.4	− 3 SD	54.4	+ 3 SD	72.4
	Cal hr^{-1}		Cal hr^{-1} mean		Cal hr^{-1}
--------------	50.1	− 3 SD	61.1	+ 3 SD	72.1
DuBois	50.6		60.0		67.8
$228.5\ W^{.55} \times H^{.4}$	48.6		61.1		70.9
$.55\ W + .2H$	51.0		60.9		70.8
Harris-Benedict	48.9		59.2		69.5
Boyd (W, H)	49.1		61.4		71.7
$3.311\ W^{.73}$ (Hem.)	45.7		61.2		75.4
$.0317\ H^{1.5}$	–		61.1		–
$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	1.482		1.247		1.087
LBW index	1.365		2.04		2.71
			H 175.3 cm. (69 in.)		
	W		W mean		W
	46.6	− 3 SD	69.6	+ 3 SD	92.6
	Cal hr^{-1}		Cal hr^{-1} mean		Cal hr^{-1}
--------------	60.3	− 3 SD	73.5	+ 3 SD	86.7
DuBois	61.5		72.9		82.3
$k\ W^{.55} \times H^{.4}$	58.1		73.5		85.3
$.55\ W + .2\ H$	60.7		73.4		86.0
Harris-Benedict	59.0		72.2		85.3
Boyd (W, H)	58.5		72.9		85.2
$3.311\ W^{.73}$	54.7		73.5		90.3
$.0317\ H^{1.5}$	–		73.5		–
$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	1.387		1.174		1.023
LBW index	1.365		2.038		2.71
			H 195.5 cm. (77 in.)		
	W		W mean		W
	58.0	− 3 SD	86.6	+ 3 SD	115.2
	Cal hr^{-1}		Cal hr^{-1} mean		Cal hr^{-1}
--------------	71.0	− 3 SD	86.6	+ 3 SD	102.2
DuBois	72.9		86.6		97.4
$k\ W^{.55} \times H^{.4}$	69.5		86.1		100.5
$.55\ W + .2H$	71.0		86.7		102.4
Harris-Benedict	69.7		86.1		102.5
$3.311\ W^{.73}$	64.3		86.0		104.5
$.0317\ H^{1.5}$	–		86.6		–
$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	1.331		1.111		0.969
LBW index	1.365		2.039		2.71

Metabolic level, 39.5 Cal $m^{-2}\ hr^{-1}$, except equation $.55\ W + .2H$ which is referable to a ML of 40 Cal $m^{-2}\ hr^{-1}$. LBW index, $\frac{\text{LBW gm.}}{H^2\ \text{cm.}}$

age group, 20 to 35 yrs.), the average of similar skin fold thicknesses was 412 mm. Again with reference to the guinea pig, the measurements of Pitts[41] indicates that the subcutaneous fat is proportional to total body fat. Hence, if this is also true in human beings, the skin fold ratio of $\frac{640}{412}$, or 1.55 supports the difference in fat content between men and women estimated to be about 5 per cent, age 25.

The Determination of Basal Metabolism

The Measurement of Metabolism. Although the procedure is simple in principle, it is frequently difficult to obtain such consistent results as those recorded by Benedict *et al.*[38] and Grollman.[42] In 1933 this author as subject obtained the following values breathing pure oxygen in a closed helmet system that eliminated the factors of resistance and CO_2 so that complete relaxation and even sleep were possible. Eliminating the first twenty-minute equilibration period, there were obtained the following mean values for successive 20 to 60 minute test periods on three occasions:

Time period (min.)		20	20	20	40	40	20	60
cc O_2/min.	1.	283	298	284	286			
	2.	289	291	280	275	284		
	3.	288	–	273	–	267*	267*	287

* asleep

Recently in the Institute of Physiology (Professor Hans Schaefer) University of Heidelberg, this author had the opportunity to serve as subject in a series of precise tests conducted by Doctor H. Goepfert and his co-workers. Action currents were recorded of muscular activity in a relaxed and then in a slightly extended position, *i.e.*, completely supine without a head pillow. The following data were recorded (subject's age, 48, H, 181 cm., W, 93 kg.):

		Cal/24 hrs.	R.Q.	cc O_2/min.
I. Subject relaxed	1.	1762	0.75	258
	2.	1738	0.73	256
	3.	1753	0.74	257
II. Subject under slight "stretch", Head pillow removed	1.	1994	0.71	295.2
	2.	1997	0.74	
III. Return to condition I	1.	1872	0.75	274.3

Subjectively the degree of relaxation felt in condition I was not experienced during condition III. Apart from an example of present day

TABLE 7

CALORIES PER HOUR FOR WOMEN, AGE 25, PREDICTED FROM FORMULAS AND FROM THE POSITION ON THEIR RESPECTIVE DISTRIBUTION CURVES OF VALUES FOR W AND CALORIES, EXPRESSED IN SD UNITS. COEFFICIENTS OF VARIATION, W, ±11%, CAL., ±6%. VALUES FOR W (15% FAT) ARE FROM TABLE 2 (COL. 6).

Formula	W	W mean	W
		H 144.8 cm. (57 in.)	
	30.9 − 3 SD	46.1 + 3 SD	61.3
	Cal hr^{-1}	Cal hr^{-1} mean	Cal hr^{-1}
------------	40.0 − 3 SD	48.8 + 3 SD	57.6
DuBois	40.4	47.9	54.1
228.5 W$^{.55}$ × H$^{.4}$	39.2	48.8	57.1
.9 (.55W + .2H)	41.4	49.0	56.4
Harris-Benedict	45.9	52.4	58.0
Boyd (W, H)	39.8	49.3	57.7
$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	1.490	1.245	1.096
LBW index	1.25	1.87	2.49
		H 162.6 cm. (64 in.)	
	W	W mean	W
	39.0 − 3 SD	58.2 + 3 SD	77.4
	Cal hr^{-1}	Cal hr^{-1} mean	Cal hr^{-1}
------------	47.6 − 3 SD	58.1 + 3 SD	68.6
DuBois	48.5	57.5	64.9
k W$^{.55}$ × H$^{.4}$	46.6	58.1	68.0
.9 (.55W + .2H)	48.6	58.1	67.5
Harris-Benedict	50.5	58.1	65.8
Boyd (W, H)	46.6	58.1	67.9
$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	1.404	1.174	1.033
LBW index	1.250	1.870	2.49
		H 180.3 cm. (71 in.)	
	W	W mean	W
	47.9 − 3 SD	71.5 + 3 SD	95.1
	Cal hr^{-1}	Cal hr^{-1} mean	Cal hr^{-1}
------------	55.6 − 3 SD	67.8 + 3 SD	80.0
DuBois	57.1	67.6	76.4
k W$^{.55}$ × H$^{.4}$	54.4	67.8	80.4
.9 (.55W + .2H)	53.8	67.0	80.0
Harris-Benedict	55.4	64.8	74.2
Boyd (W, H)	53.8	67.0	78.3
$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	1.337	1.115	0.995
LBW index	1.250	1.870	2.490

Metabolic level, 39.5 Cal m^{-2} hr^{-1}, except equation .9(.55 W+.2 H) which is referable to a level of 36 Cal m^{-2} hr^{-1}.

meticulous technic of measuring standard metabolism, this experiment demonstrates the influence of a single factor, muscular stretch (postural contraction), an oxygen uptake (FIGURE 12). This variability, in combination with additional deterrents to accuracy such as respiratory re-

TABLE 8

ESTIMATED METABOLISM PER KILOGRAM OF LEAN BODY WEIGHT FOR MEN AND WOMEN, AGE 25.

Men						Women				
cm.	$H_{in.}$	W (1)	LBW (2)	Cal hr^{-1} (3)	$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$	$H_{in.}$	W (4)	LBW (5)	Cal hr^{-1} (6)	$\frac{\text{Cal hr}^{-1}}{\text{LBW}}$
195.5	77	86.6	77.9	86.6	1.112					
193.0	76	84.4	76.0	85.0	1.118	71	71.5	60.8	67.8	1.115
190.5	75	82.2	74.0	83.3	1.126	70	69.5	59.1	66.4	1.124
188.0	74	80.1	72.1	81.7	1.133	69	67.6	57.5	65.0	1.130
185.4	73	77.9	70.1	80.0	1.141	68	65.6	55.8	63.6	1.140
182.9	72	75.9	68.3	78.4	1.148	67	63.7	54.2	62.2	1.148
180.3	71	73.9	66.5	76.8	1.155	66	61.8	52.5	60.8	1.158
177.8	70	71.6	64.5	75.1	1.166	65	60.0	51.0	59.5	1.167
175.3	69	69.6	62.6	73.5	1.174	64	58.2	49.4	58.1	1.176
mean						mean				
172.7	68	67.6	60.8	71.9	1.183	63	56.3	47.9	56.7	1.184
170.2	67	65.6	59.1	70.3	1.192	62	54.6	46.4	55.4	1.194
167.6	66	63.7	57.3	68.8	1.200	61	52.8	44.9	54.0	1.203
165.1	65	61.8	55.6	67.3	1.210	60	51.1	43.4	52.7	1.214
162.6	64	59.9	53.8	65.7	1.219	59	49.4	42.0	51.5	1.226
160.0	63	58.0	52.2	64.1	1.228	58	47.7	40.6	50.1	1.234
157.5	62	56.2	50.6	62.6	1.237	57	46.1	39.2	48.8	1.245
154.9	61	54.4	49.0	61.1	1.247					

(1) $W = .00227\ H^2$

(2) $LBW = .00204\ H^2$, (.9 W), LBW index, 2.04

(3) Cal $hr^{-1} = 228.6\ W^{.55} \times H^{.4} \times$ Metabolic level factor, 39.5 Cal $m^{-2}\ hr^{-1}$

(4) $W = .00223\ H^2$

(5) $LBW = .00187\ H^2$, (.85 W), LBW index, 1.87

(6) Cal hr^{-1} = formula (3) × Metabolic level factor, 35.5 Cal $m^{-2}\ hr^{-1}$

sistance and accumulation of CO_2 (in closed circuits) is why basal metabolism usually cannot be measured as accurately as it can be predicted.

An example of the calculation of LBW from observed M may be given from the data recorded above: Subject, age 48, H, 181 cm., W, 93 kg.

$$M\ (O_2/\text{min.}) = 257\ \text{cc}\ (74.5\ \text{Cal hr}^{-1})$$

$$\text{LBW} = \frac{\text{Cal hr}^{-1} - .2\ \text{H}}{.6033}, \qquad \text{metabolic level, 39.5 Cal m}^{-2}\ \text{hr}^{-1}.$$

$$\text{Age correction} = (48\text{-}25)\ .2\% = 4.6\%;\ .6033 \times (1 - .046) = .575$$

$$\text{LBW} = \frac{74.5 - 36.2}{.576} = 66.3\ \text{kg.}$$

The subject's LBW during the past 14 years based on specific gravity and total body water determinations, has been recorded as 70.5, 73.8, 70.7 and 70.3 kg. The difference (about 6 per cent) between LBW estimated from basal metabolism and that determined by other technics, illustrates the limitations in using a function influenced by several variables, *i.e.*, the correction factor for age may have been too low (premature ageing), the metabolic level (39.5 Cal), too high, or the subject's metabolism abnormally low. A value of 37.5 Cal (Krogh) may have been the more correct metabolic level in view of the subject's unusual ability to "relax."

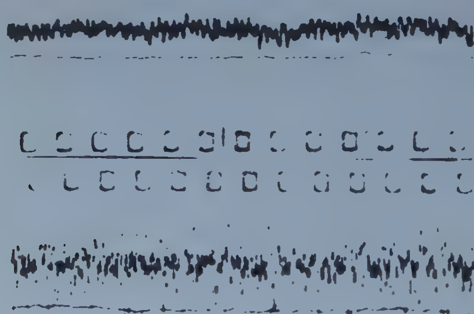

FIGURE 12. Recordings of the action currents from the resting muscles of the arm during basal metabolism tests. When the upper recording was made, the subject was relaxed; oxygen consumption, 256 cc/min. A pillow was then removed which had supported the subject's head. Although there was no voluntary movement, some degree of stretching was experienced and it was accompanied by an augmented oxygen utilization of 295 cc/min. (From an experiment conducted by Dr. H. Goepfert, Laboratory of Professor Hans Shaefer, University of Heidelberg).

Comments

Surface Area, Weight, Height Relationship. That one of the most difficult measurements to make in biology, namely that of surface area, can be estimated accurately from height and weight parameters, is puzzling. If stature were combined, not with W, but with a circumferential measurement, a comparison could readily be made with a

geometrical figure. Von Schelling,[43] however, has been able to show a type of geometrical model for which surface area is proportional to $W^{.73 \text{ to } .75}$ and from which relationships applicable to man can be derived. He has also been able to show that the interspecific formula does not permit more latitude in the range of the exponent, .73, than ±.01. This restricted range is related to a limiting minimal weight value possible for homoiotherms.

In animal husbandry one would anticipate that there exist also the same "bidimensional" relationships that apply to man, if one were to evaluate critically M in relation to body size. The second "dimension" might conceivably be one, or a summation of circumferential *skeletal* measurements. For men such measurements are much needed for the object of providing an estimate of the weight of the normal lean body mass not only in healthy individuals but also in patients.

The Basic Relationship Between LBW and M. From the distribution of blood flow to various organs under basal conditions (Jones[44]), it is a reasonable conclusion that about two thirds or more of basal M is "visceral" and the remainder, "skeletal". When one considers the disproportion between organ weight and the respiration of various organs and tissues, it is amazing that M is so nicely proportional to a fractional power of weight. Kleiber[45] states this succinctly, "if the metabolic rate of an animal is the sum of the metabolic rates of all of its tissues, then the metabolic rate per gram of tissue *in vivo* is inversely proportional to the 4th root of body weight. This may or may not be true for each tissue but it must be true for the sum.....".

Insight into this problem was afforded by the classical experiments of Field, Belding, and Martin[46] concerned with comparison of basal M in the intact rat and a summation of respiration of the various isolated tissues of the rat's body. Two thirds of the basal metabolism could be accounted for directly from the summation of respiration of the individual tissues. In the live animal functional activity, particularly of muscles (postural contraction; the importance of this factor was evident in the Heidelberg experiments cited), brain, and basal level of cardiac, respiratory, smooth muscle, and secretory function, amounts to more than 25 per cent of the resting oxygen consumption. Probably, therefore, there is quantitative agreement between summated tissue respiration and M in the living animal. This goes far in explaining the nicety of the metabolism-body weight relationship.

Kleiber,[47] and Weymouth, Field and Kleiber[48] found that metabolism of homologous tissues of several species, notably liver, paralleled total M of the animals from which the tissue was removed. Krebs,[49] although he confirmed in the main the results with reference to liver slices, concluded that there was no strict parallelism for brain, kidney,

the intact animal. The musculature was regarded as perhaps one major tissue whose "basal" Q_{O_2} changes with body weight, might parallel basal heat production.

Slope and Nature of the Metabolism-Weight Regression Line for Specific Statures. It is apparent that measurements are required of M in individuals of known body composition whose lean body weights for a given stature are separated by 4 to 6 SD, *i.e.*, a LBW index for one group of about 1.4 compared with that of another group of 2.6. In connection with the preceding paragraphs, however, there is the more refined approach to this problem inherent in measurements of tissue respiration, say of liver slices removed from adult animals of the same species who differ greatly in LBW along line CD, rather than AB, FIGURE 9. If the studies of Pitts[41] now in progress confirm his preliminary observations that liver weight is proportional to LBW, then the component liver may replace its parent body, the LBM, in the distribution parallelogram (FIGURE 11). One would anticipate a difference of as much as 50 per cent in the respiration of isolated liver slices from normal adult animals at opposite ends of the distribution scale.

Physical Classification of Individuals. The wide range of oxygen consumption per unit of body weight suggests why "normal" men may manifest such marked differences in function and in their responses, even under carefully standardized conditions.

Because the gross composition of the lean body mass is constant, the LBW lends itself to exact placement on the normal distribution curve, where its location can be designated by multiples or fractions of the SD or of the coefficients of variation. The range of normality is not confined to mean weights relative to statures on the general population curve, but it is extended over a range of LBW values from 33 to some 103 kg.

For each LBW there then may be predicted accurately, the total amount of body water, the size of the extracellular fluid compartments, and even the variable blood volume when standard conditions are extended to include the state of physical training of the individual. For example, data from the report of Dahlstrom[21] examined by the author show that the thiocyanate space in two sets of experiments conducted by different investigators, was sharply limited to between 26 and 28 per cent of the LBW. From the precise CO determinations of blood volume by Kjellberg, Rudhe, and Sjostrand,[50] it can be calculated that the mean blood volume in untrained individuals is 8.8 per cent of the mean LBW for men and 8.6 per cent of the mean LBW for women. These authors further demonstrated the high correlation between blood volume and heart volume, and that the ratio of blood volume to heart volume

was of the same order of magnitude for men, women, and children. There was further a high negative correlation between log $(\frac{\text{pulse rate}}{\text{Calc. BMR}})$ and log (hemoglobin).

The list of components and functions can be extended to include the size of various organs relative to LBW and cardiac output. Those functions proportional to surface area would be expected to have coefficients of variation of the order of 6 per cent, those proportional to LBW, 11 per cent.

Morales *et al.*,[51] have treated the body as a five phase system and they have developed equations which relate each tissue component to body weight and to average body density. Adolph[52] has emphasized the quantitative orderliness of physical constitution and physiological processes of organisms. Some 34 correlations were represented nomographically for mammals, so that from a single measurement of anyone the other 33 could be read. Determinations of standard metabolism and LBW should further the partitional analyses of Morales, Adolph, Moore *et al.*,[53] Edelman[54] and McCance and Widdowson,[55] so that the body as a whole and its gross components and functions can be estimated for each individual in accordance with his position within the LBW parallelogram. These macro biochemical and functional analyses preserve and enhance the picture of the individual as a whole even though the mosaic pattern of component parts is delineated at the same time quantitatively.

Concluding Note. There are many problems and relationships, as well as implications in the graphic and tabular presentation which have not been brought out. This analysis cannot be concluded, however, without reemphasizing the importance of basal metabolism as outlined by Benedict[1] in his summary monograph. The work of Wetzel[56] also is of special importance not only because his predicated 5 channels of development in children can be projected into a similar division of lean body weights in adults according to their position on the normal distribution scale, but also because of the importance he attributed to basal metabolism in the evaluation of childhood development. His isodevelopmental lines are interpreted as iso-surface area contours and for their estimation the extended interspecies formulation of Hemmingsen and others, was applicable.

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